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Bethesda, Md. 20084

A COMPUTER PROGRAM FOR THE PRELIMINARY DESIGN OF CONTRAROTATING PROPELLERS

by

E. B. Caster and T. A. LaFone

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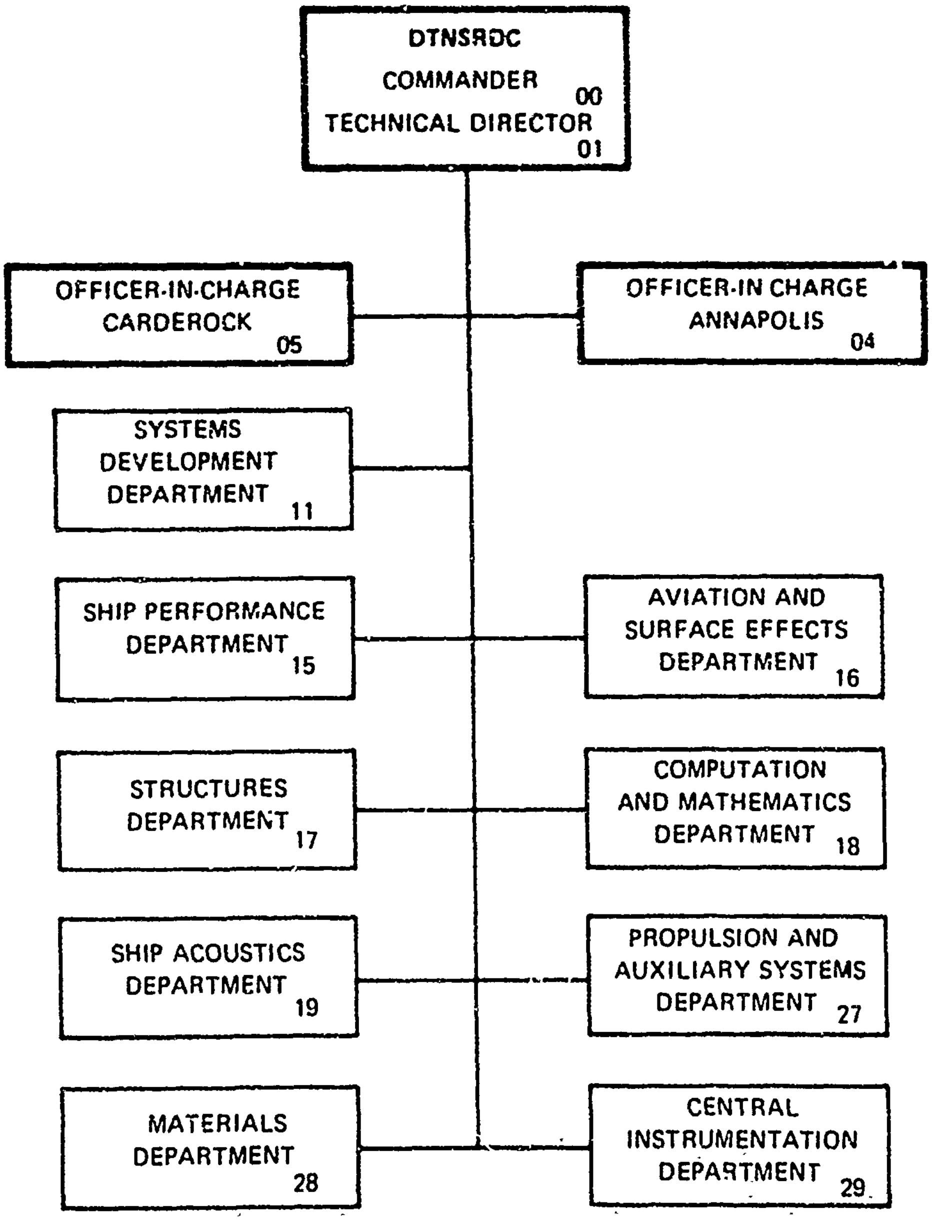

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This report presents a new computer program that can be used to design and predict the performance of contrarotating propellers. The new propeller utilizes the latest numerical computation techniques developed for the design of contrarotating propellers. The hydrodynamic pitch angle distribution is specified as input and the design calculations are made using Lerb's moderately loaded single screw lifting line propeller theory. The propeller interaction effects (the most important new feature of the design procedure) are obtained using Kerwin's field point velocity program developed using finite bladed lifting over

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surface theory.

An analysis of results obtained for a sample set of contrarotating propellers, designed using the new method presented, show that different design and performance predictions are obtained for the aft propellers when results are compared to those calculated using the old method. Calculations made using the new design method are considered more accurate due to the improved method of determining the propeller interaction effects.

A FORTRAN listing of the new propeller, developed to run on the computer at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) is presented as well as input and output obtained for a sample set of contrarotating propeller designs.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

NOTATION

A_E	Expanded blade area, $Z\int_{r_h}^{R} c\,dr$
A_E/A_O	Propeller expanded area ratio, $(2Z/\pi)\int_{x_h}^{1} c/D\,dx$
$(A_E/A_O)_k$	Keller's minimum expanded area ratio for eliminating back bubble cavitation, $(2.6+0.6Z)K_T/\{\sigma_{0.7}[J^2+(0.7\pi)^2]\}+K$
A_O	Disc area, $\pi D^2/4$
A_P	Estimated propeller projected area, $[1.067-0.229(P/D)_i]A_E$
$a(x)$	Area of section, $2\,c(x)t(x)\int_0^1 t(x,x_\ell)\,dx$
$B(x)$	Distance of CG from face, $\bar{y}\cos\phi + \bar{x}\sin\phi - \theta_S\, x\, R\tan\phi - \theta_R\, x + D_H/2$
$(c/R)_{LE}, (c/R)_{TE}$	Chord lengths measured from leading edge and trailing edge of blade to propeller reference line
C_D	Section drag coefficient
C_{FO}	Frictional resistance of section
CG	Center of gravity
C_L	Blade section lift coefficient
C_P	Power loading coefficient, $P_D/[(\rho/2)\pi R^2 V_A^{\,3}]$
C_{PS}	Power loading coefficient based on ship speed, $P_D/[(\rho/2)\pi R^2 V^3]$; calculated $\int_{x_h}^{1}(1+\varepsilon/\tan\beta_I)(dC_{PSi}/dx)\,dx$
C_{TS}	Thrust loading coefficient based on ship speed, $T/[(\rho/2)\pi R^2 V^2]$; calculated $\int_{x_h}^{1}(1-\varepsilon\tan\beta_I)(dC_{TSi}/dx)\,dx$
c	Propeller blade chord length, $c(x)$
C_{PSi}	Inviscid power loading coefficient, $(4Z/\lambda_s)x\,G\,[(1-w_x)+U_T/2V]$
C_{TSi}	Inviscid thrust loading coefficient, $4ZG(x/\lambda_s-U_A/2V)$

D	Propeller diameter
d_H	Hub diameter
$F(x)$	Parameter for calculating the fluctuating angles of attack, $1/\{1+2\pi\tan(\beta_I-\beta)/C_L\}$
f_M	Camber
g	Acceleration due to gravity
g_a	Lerbs axial distance factors (Reference 1)
$G(r)$	Nondimensional circulation about a blade section, $\Gamma/(2\pi RV)$
G_F	Spacing between fillets
G_Z	Spacing between blades at hub
H	Static head at propeller shaft centerline
I_{xo}, I_{yo}	Moment of inertia of blade section about x and y axes
J	Advance coefficient, $V(1-w_T)/(nD)=V_A/(nD)$
J_V	Ship speed advance coefficient, $V/(nD)$
K	Kellers' constant for predicting minimum blade area of propeller (see p. 24)
K_Q	Torque coefficient, $Q/(\rho n^2 D^5)$
K_T	Thrust coefficient, $T/(\rho n^2 D^4)$
LI	Propeller lift distribution per unit span for finite element stress calculations
M_P	Moment of blades (see p. 24)
M_{Tb}, M_{Qb}	Moment due to thrust and torque
M_{xo}, M_{yo}	Moment parallel and perpendicular to the nose-tail line
n	Propeller revolution per unit time

$(P/D)_i$	Estimated propeller pitch ratio at 0.7 radius, $0.7\pi\tan\beta_I$ in program
P_D	Delivered power at propeller, $2\pi Qn$
P_E	Effective power
P_S	Shaft power
Q	Propeller torque
R	Propeller tip radius
r	Propeller local radius
r_h	Propeller hub radius
r_ℓ	Local position along the section chord
T	Propeller thrust
t	Propeller blade maximum thickness $t(x)$, thrust deduction fraction
$t(x,x_\ell)$	Chord wise distribution of section thickness (NACA 66 modified thickness form is used)
$U_A/2V$	Axial induced velocity at lifting line
$U_T/2V$	Tangential induced velocity at lifting line
V	Ship speed
V_A	Speed of advance of the propeller, $V(1-w_T)$
V_x	Local velocity along the x axis at any field point
V_r	Inflow velocity at each propeller section, $V\sqrt{[(1-w_x)+U_A/2V]^2+[x/\lambda_s-U_T/2V]^2}$
w_a/V	Axial velocity from sources other than the propeller wake $(1-w_x)$
W_B	Weight of blades
W_H	Weight of hub
W_P	Propeller weight

w_c	Circumferential mean wake fraction at each radius calculated from wake survey
w_t/V	Tangential wake velocities from sources other than the propeller wake $(1-w_x)$
w_T	Propeller effective wake fraction as determined from thrust identity from self propulsion experiment
w_v	Volume mean wake fraction
w_x	Propeller wake fraction
x	Nondimensional radial distance, r/R
x_h	Nondimensional hub radius, (r_h/R)
x_ℓ	Nondimensional distance along section chord, (r_ℓ/c)
Z	Number of blades
Z_R	Propeller rake
Z_T	Total rake, rake plus induced rake
α_i	Section ideal angle of attack, $1.54C_L$ for NACA a=0.8 meanline in two-dimensional flow
α_{max}	Maximum fluctuating angle of attack, $\alpha_i-(-\Delta\beta)F(x)$
α_{min}	Minimum fluctuating angle of attack, $\alpha_i-(+\Delta\beta)F(x)$
β	Advance angle of a propeller blade section
β_I	Hydrodynamic flow angle of a propeller blade section
Γ	Propeller circulation, $2\pi RVG$
ε	Section drag-lift ratio, C_D/C_L
η_D	Propulsive efficiency, $P_E/P_D=(1-t)C_{TS}/C_{PS}$
θ_R	Blade rake angle in degrees (see p. 15)
θ_S	Blade skew angle in degrees (see p. 15)

λ_S	Advance ratio of propeller based on ship speed, V/(nD)
ρ	Water density
ρ_P	Density of propeller material
ϕ	Pitch angle
σ	Section cavitation number, $2gH/V_r^{\ 2}$
$\sigma_{0.7}$	Burrill cavitation number, $2gH/\{(V(1-w_{x=0.7}))^2+(0.7\pi nD)^2\}$
τ_c	Burrill thrust loading coefficient, $2gH/\{(V(1-w_{x=0.7}))^2+(0.7\pi nD)^2\}$

ABSTRACT

This report presents a new computer program that can be used to design and predict the performance of contrarotating propellers. The new program utilizes the latest numerical computation techniques developed for the design of contrarotating propellers. The hydrodynamic pitch angle distribution is specified as input and the design calculations are made using Lerbs' moderately loaded single screw lifting line propeller theory. The propeller interaction effects (the most important new feature of the design procedure) are obtained using Kerwin's field point velocity program developed using finite bladed lifting surface theory.

An analysis of results obtained for a sample set of contrarotating propellers, designed using the new method presented, show that different design and performance predictions are obtained for the aft propeller when results are compared to those calculated using the old method. Calculations made using the new design method are considered more accurate due to the improved method of determining the propeller interaction effects.

A FORTRAN listing of the new program, developed to run on the computers at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) is presented as well as input and output obtained for a sample set of contrarotating propeller designs.

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INTRODUCTION

The David W. Taylor Naval Ship Research and Development Center (DTNSRDC), Carderock Laboratory, was requested by the Naval Sea Systems Command (NAVSEA) to develop a computer program that can be used to better design and predict the propulsive and cavitation performance of contrarotating propellers. Contrarotating propellers have been used on naval vessels, especially torpedoes, because they offer advantages over single-screw propellers by being more efficient, having smaller optimum diameters, and being torque-balanced resulting in better stability. Unfortunately, the contrarotating propeller theory and design procedure have not kept pace with the advancement developed for single-screw propellers where the design and performance predictions can be made with a high degree of accuracy.

The old contrarotating propeller design procedure used at DTNSRDC is based on Lerbs' theory of References 1, 2, and 3. This method requires that the same hydrodynamic pitch distribution be specified as input for the forward and aft propellers and results obtained show that similar circulation distributions are computed for both propellers. The average axial and tangential propeller induced velocities used to determine the propeller interaction effects are derived using the uniformly loaded sink disc theory in this design method.

DTNSRDC is presently evaluating a package of contrarotating propeller design computer programs based on lifting line and lifting surface theories, recently developed by Nelson in Reference 4. The propeller lifting line theory used requires the circulation distribution (which must be the same for the forward and aft propellers) rather than the hydrodynamic pitch distribution, to be specified as input. The corresponding hydrodynamic pitch distribution is calculated using Lerbs' moderately loaded single screw theory

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1. Lerbs, H.W., "Contra-Rotating Optimum Propellers Operating in a Radially Non-Uniform Wake," David Taylor Model Basin Report 941, May 1955
2. Morgan, William B. and Wrench, J.W., Jr., "Some Computational Aspects of Propeller Design," Methods in Computational Physics, Vol. 4, academic Press Inc., New York, p 301-331, 1965
3. Morgan, W.B., "The Design of contrarotating Propellers Using Lerbs' Theory," Transactions of the Society of Naval Architects and Marine Engineers, vol. 68, p 6-38, 1960
4. Nelson, D.M., "A Computer Program Package for Designing Wake-Adapted Counterrotating Propellers: A Users Manual," Naval Undersea Center, Fleet Engineering Department Report NUC TP 494, December 1975

of Reference 5, which has been extended to account for finite circulation values at the propeller hub. Nelson's method for determining propeller interaction effects (average axial and tangential propeller induced velocities) are determined using the procedure developed by Hough and Ordway in Reference 6, corrected to account for finite blade number effects. Preliminary results from Nelson's computer program for making pitch and camber calculations based on contrarotating propeller lifting surface theory show that lifting surface effects due to the forward and aft propellers are small.

The new contrarotating propeller design computer program based on Lerbs moderately loaded single screw propeller theory of Reference 5 is similar to the computer program developed for single screw propellers in Reference 7 except that additional calculations are required to account for propeller interaction effects required in the contrarotating propeller design program. The average axial and tangential propeller-induced velocities needed to determine the propeller interaction

5. Lerbs, H.W., "Moderately Loaded Propellers with a Finite Number of Blades and an Arbitrary Distribution of Circulation," Transactions of the Society of Naval Architects and Marine Engineers, Vol. 60, p 73-117, 1952
6. Hough, G.R. and Ordway, D.E., "The Generalized Actuator Disk," Advanced Research Report TAR-TR-6401, Therm, Inc., January 1964
7. Caster, E.B., Diskin, J.A., and LaFone, T.A., "A Lifting Line Computer Program for the Preliminary Design of Propellers," David W. Taylor Naval Ship Research and Development Center Report SPD-595-01, November 1975

effects are derived using Kerwin's field point velocity program described by Denny in Reference 8. These calculations represent the most important new feature of the design procedure presented. Unlike the old method[1,2,3], the new contra-rotating propeller design computer program allows different hydrodynamic pitch distributions, wake distributions and rpm values to be specified as input for the forward and aft propellers. Nelson's lifting surface theory[4] for contrarotating propellers should be used to calculate the final pitch and camber for these propellers. Preliminary results using Nelson's lifting surface theory show that the lifting surface interaction effects due to the forward and aft propellers are small. As a result, lifting surface theory developed for single screw propellers (Reference 9) may be used to determine the final pitch and camber for the contrarotating propellers if Nelson's program is not available. The estimated propeller stresses are calculated based on simple beam theory[10] modified to account for effect of rake and skew. The propeller weight, spacing between propeller blades, chord lengths for lifting surface pitch and camber calculations and blade load distributions

8. Denny, Stephen B., "Comparisons of Experimentally Determined and Theoretically Predicted Pressures in the Vicinity of a Marine Propeller," Naval Ship Research and Development Center Report 2349, May 1967
9. Morgan, W.B., Silovic, Vladimir, and Denny, S.B., "Propeller Lifting Surface Corrections," Transactions of the Society of Naval Architects and Marine Engineers, Vol. 76, p 309-347, 1968
10. Eckhardt, M.K. and Morgan, W.B., "A Propeller Design Method," Transactions of the Society of Naval Architects and Marine Engineers, Vol. 63, p 325-370, 1955

for finite element stress calculations are also included in the calculations made using this method. Parameters for calculating the minimum expanded area ratio by Keller[11] and the methods of Burrill[12] and Brockett[13] are used to check the cavitation performance of each propeller. An input option to specify the hull radial induced velocity (not available in the program presented) would also improve the accuracy of the design calculations.

PROPELLER LIFTING-LINE THEORY

As mentioned in the Introduction, the new contrarotating design procedure follows closely Lerbs' moderately loaded, single-screw lifting-line propeller theory[5] as described in Reference 7. Kerwin's field point velocity program[8] is used to determine the propeller interaction effects (average axial and tangential propeller-induced velocities). The diameter of the aft propeller is based on contraction of the slip stream. These calculations are made using the continuity equation as described in Reference 1, once Lerbs' distance factors (g_a) values, plotted in Figure 1, are specified. More exact contraction of the slip stream calculations can be made using

11. Keller, J. Auf'm, "Enige aspecten bij het ontwerpen van Scheepsschroeven," SChip en werf, No. 24, p 658-662, 1966
12. Burrill, L.C. and Emerson, A., "Propeller Cavitation: Further Tests on 16-Inch Propeller Models in the Kings College Cavitation Tunnel," Transactions of the North East Coast Institution of Engineers and Ship Builders, Vol. 78, p 295-320, 1963-64
13. Brockett, Terry, "Minimum Pressure Envelopes for Modified NACA 66 Sections with NACA a=0.8 Camber and BUSHIPS Type I and Type II Sections," David Taylor Model Basin Report 1780, 1966

the propeller-induced field point velocity program of Reference 8 if velocities are calculated at a sufficient number of points. This approach was not used in the program presented because it would result in a significant increase in the core size and running time of the computer program.

The main steps in the new contrarotating propeller design procedure presented are as follows:

1. Lerbs' moderately loaded single-screw lifting-line propeller theory[5] is used to make design calculatons for the forward propeller. The average axial and tangential velocities induced by the aft propeller on the forward propeller are not included initially in these calculations, but must be included in subsequent calculations.
2. Lerbs' contrarotating (equivalent) propeller design procedure[1] is used to calculate the aft propeller diameter.
3. Kerwin's field point velocity program described in Reference 8 is used to compute the average axial and tangential velocities induced by the forward propeller on the aft propeller.

4. The aft propeller design calculations are made using Lerbs' moderately loaded single-screw lifting-line propeller theory[5] where the average axial and tangential velocities induced by the forward propeller on the aft propeller (step 3) are included in the aft propeller calculations. These steps (1 through 4) are repeated until the propeller-induced velocities converge.

DESCRIPTION OF INPUT DATA

Appendix A presents a list of dimensioned propeller design parameters required for the new computer program developed which must be in the international system of units (SI units). This list also contains conversion factors (K_{SI}) for changing dimensioned parameters from SI units to English units. Effective power (P_E), speed (V), number of blades (Z), diameter (D), propeller wake ($1-w_x$), the hydrodynamic flow angle distribution (β_I) and distance factors (g_a) from Figure 1 are required input parameters in order to make nonviscous propeller design calculations based on lifting-line theory. The radial distribution of blade chord lengths, nondimensionalized on diameter, (c/D) and section drag coefficients (C_D) must be specified as input if design calculations are to account for the viscous

drag effects on the blades. The radial distribution of maximum thickness nondimensionalized on chord length (t/c), blade rake angle (θ_R), and skew angle (θ_S) parameters are input so propeller stresses based on beam theory of Reference 10 can be calculated. The static head (H) is input so the blade section cavitation number (σ) can be computed. Appendix A also gives the complete input format (card numbers, format and description of input parameters) for the computer program. A brief description of how some of these parameters can be determined will be discussed next.

Effective Power, Speed, and Shaft Power

Effective power and speed are normally obtained from model self-propulsion experiments. Input effective power (P_E) and shaft power (P_S) are defined as follows:

$$P_E=VT(1-t) \tag{1}$$

$$P_S=2\pi nQ \tag{2}$$

where n = propeller revolutions

P_S = shaft power,

P_E = effective power,

Q = propeller torque,

T = propeller thrust,

V = ship speed, and

(1-t) = thrust deduction, which may vary with propeller diameter and speed.

Nondimensional Radial Distance (x)

This is a reference set of eleven nondimensional radial distances x_i at which all other distributions, either input or calculated by the computer, are defined as existing. In general, $x_i = r_i/R$, with the restrictions

$x_1 = r_h/R$

$x_{11} = R/R=1,$

where r_i = the distance along the propeller reference line from the shaft axis to the ith section,

r_h = propeller hub radius, and

R = propeller tip radius.

Propeller Wake

The radial distribution of the axial wake $(1-w_x)$ which varies with propeller diameter is also required input data. The circumferential mean of the axial velocity distribution $(1-w_c)$ is obtained from a wake survey without the propeller operating. However, the $(1-w_c)$ wake distribution must be corrected for the propeller action. No completely satisfactory method is presently available to obtain this correction, but an approximation of the radial distribution of the wake $(1-w_x)$ with the propeller operating is obtained as follows:

Wake distribution

$$(1-w_x) = \left((1-w_T)(1-w_C)\right)/(1-w_v) \tag{3}$$

where $(1-w_C)$ = radial distribution of the circumferential mean wake from wake survey data,

$(1-w_T)$ = effective wake from self propulsion data

$(1-w_v)$ = volume mean wake, $\left(2/(1-x_h^2)\right)\int_{x_h}^{1} (1-w_x)\, x dx$,

R = propeller radius,

r = propeller local radius,

r_h = propeller hub radius,

x = nondimensional radial distance (r/R), and

x_h = nondimensional hub radius (r_h/R).

The propeller wake distribution may also vary with propeller diameter depending on the hull characteristics of the vessel.

Advance Angle Distribution Option

The advance angle distribution ($\tan\beta$) defined as $V(1-w_x)/(\pi nDx)$ is normally calculated on the computer for the case where the propeller wake $(1-w_x)$ from Equation (3) sufficiently represents wake in the plane of the propeller being designed. For most single screw propeller designs this approach gives good performance predictions. If a propeller operates inside a duct or in the vicinity of another propeller as in the case of tandem or contrarotating propellers, the axial (w_a/V) and tangential (w_t/V) velocities induced by these additional sources can be accounted for using

different methods. For contrarotating propellers, the propeller interference velocities are computed using Kerwin's field point velocity program described in Reference 8 in the following manner:

$$\tan\beta = \left[(1-w_x)+w_a/V\right]/\left[(x/\lambda_s)-w_t/V\right] \quad (4)$$

where w_a/V = axial velocity induced by forward and aft propellers on each other,

w_t/V = tangential velocity induced by forward and aft propeller on each other,

λ_s = advance ratio based on ship speed, $V/(\pi n D)$

V = ship speed, and

D = propeller diameter.

It can be seen from Equation (4) that for the case where (w_a/V) and (w_t/V) values are specified as zero, the advance angle $\tan\beta$ is calculated in the usual manner when designing single screw propellers.

Hydrodynamic Flow Angle

The hydrodynamic flow angle distribution ($\tan\beta_I$) can be specified as input. An option is included so Lerbs' optimum $\tan\beta_I$ distribution[10] can be calculated by the computer as follows:

$$\tan\beta_I = (\tan\beta/\eta_i)\left[(1-w_T)/(1-w_x)\right]^{1/2} \quad (5)$$

where η_i = propeller ideal efficiency

$\tan\beta$ = advance angle distribution.

Lerbs' optimum $\tan\beta_I$ distribution usually results in optimum propeller efficiency. If other factors such as cavitation, strength and vibration are considered, the input of an alternate $\tan\beta_I$ distribution may be desired.

Static Head

The static head (H) at the shaft centerline is required input. This parameter (H) is defined as $H_s+H_a-H_v$, where H_s is the shaft submergence, H_a is the atmospheric pressure, and H_v is the vapor pressure of fluid which is normally small compared with H_a and may be neglected. The static head (H) is used to calculate the section cavitation number (σ) in Equation (25) and the Burrill cavitation number $\sigma_{0.7}$ of Equation (30).

Blade Outline and Expanded Area Ratio

The blade outline (c/D) and expanded area ratio (A_E/A_0) must be input for the design. An expanded area ratio (A_E/A_0) is calculated on the computer according to:

Expanded Area Ratio:

$$A_E/A_O = (2Z/\pi)\int_{x_h}^{1} c/D\ dx \qquad (6)$$

where c = chord length,

c/D = nondimensional chord length

Z = number of blades

The final blade outline and expanded area ratio should be chosen to give satisfactory propeller strength and cavitation characteristics.

Blade Thickness to Chord Ratio

The input of maximum thickness to chord ratio (t/c) values allow an estimate of the propeller principal stresses (see The Propeller Stress Calculations Using Beam Theory section discussed later) based on beam theory[10] to be calculated during the preliminary design stage of the propellers. From a rough estimate of the blade outline (c/D) for the final design and an estimate of the radial distribution of thickness (t/D) based on fatigue strength[10], the following equation can be used to obtain initial (t/c) input values:

Blade Thickness Ratio:

$$t/c = (t/D)/(c/D) \qquad (7)$$

where t/D = radial distribution of thickness (can be estimated from Reference 10.

Rake and Skew

The rake angle at the blade tip (θ_R) and the skew angles (θ_s) for a design are specified to permit adequate predictions of principal propeller stresses using the beam theory method described in Reference 10 and discussed later in the Propeller Stress section of this report.

The rake (θ_R) is defined consistent with Reference 14 as the distance from the propeller plane to the generator line in the direction of the shaft axis. Aft displacement is considered positive rake.

Since the skew angles (θ_S) significantly affect propeller unsteady forces, a computer program based on the unsteady contrarotating propeller lifting surface theory of Reference 15 can be used to select the skew angles (θ_S) for the design. The input skew angles (θ_S) in degrees are defined as the angular displacement of points on the blade reference line from the propeller reference line in the projected view.

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14. Cumming, R.A., Dictionary of Ship Hydrodynamics - Propeller Section, 14th International Towing Tank Conference 1975, Report of Presentation Committee, Appendix VII, 1975
15. Tsakonas, J. and Jacobs, W.R., "Counterrotating and Tandem Propellers Operating in Spacially Varying, Three-Dimensional Flow Fields," Davidson Laboratory, Stevens Institute of Technology Report 1335, September 1968

Section Drag Coefficient

In order to account for viscous effects when predicting the performance of a propeller, the section drag coefficient (C_D) must be specified as input. A section drag coefficient (C_D) value of 0.0085 usually gives reasonable estimates of model propeller drag for propeller shapes normally used at DTNSRDC in the past. For propellers having very thick blades, the following equation, available as an input option on the computer, and derived as a function of maximum thickness (t/c) values using experimental data from NACA 66 type section[16,17], will give a better estimate of the section drag coefficient (C_D):

Section Drag Coefficient:

$$C_D = C_{FO}\left[1+1.25(t/c) + 125\ (t/c)^4\right] \tag{8}$$

where C_{FO} is the frictional resistance of the section, e.g., $C_{FO} \approx 0.008$ for Reynolds number of approximately 10^6 and $C_{FO} \approx 0.004$ for Reynolds number of approximately 10^8. Options for using alternate nonlinear C_D distributions, or a constant C_D distributions are also available.

Lerbs Axial Distance Factors

It was noted earlier that Lerbs' axial distance factors (g_a), rather than the use of the more correct propeller-induced velocities from Reference 8, were used to obtain

16. Abbot, Ira H. and Von Doenhoff, Albert E., "Theory of Wing Sections Including a Summary of Airfoil Data," Dover Publication Inc., New York, Library of Congress Catalog No.: 60-1601, 1949
17. Hoerner, S.F., "Fluid-Dynamic Drag," Published by the author, Midland Park, New Jersey, 1965

contraction of the slip stream and the aft propeller diameter in order to minimize core size and running time of the computer program. The ς_a values from Reference 1, plotted as a function of propeller radius and spacing between propeller blade center lines, are presented in Figure 3.

DESCRIPTION OF OUTPUT DATA

Lerbs' lifting line theory is used to calculate the propeller lift coefficient (C_L), nondimensional circulation (G), hydrodynamic flow angle (β_I), axial induced velocity ($U_A/2V$), and tangential induced velocity ($U_T/2V$). These lifting-line calculations take into account viscous drag effects on the propeller by specifying as input in the computer program the propeller section nondimensional chord length (c/D) and section drag coefficient (C_D). A method for obtaining values for c/D and C_D is discussed in the Description of Input Data section of this report. With these parameters available, the necessary design and performance prediction parameters for contrarotating propellers can be obtained.

Thrust and Power Loading Coefficients, and Propulsive Efficiency

The new contrarotating propeller design computer program calculates the thrust (C_{TS}) and power (C_{PS}), loading coefficients based on ship speed and the estimated propulsive efficiency (η_D)

for these propellers in the following manner:

Thrust Loading Coefficient:

$$(C_{TS_e})_{fwd,aft} = \int_{x_h}^{1} (1-\varepsilon\tan\beta_I)/(dC_{Tsi}/dx)\,dx = T/\left((\rho/2)\pi R^2 V^2\right) \quad (9)$$

$$(C_{Ts})_{CR} = (C_{Ts})_{fwd} + (R_{aft}/R_{fwd})^2\ (C_{Ts})_{aft} \quad (10)$$

Power Loading Coefficient:

$$(C_{PS_e})_{fwd,aft} = \int_{x_h}^{1} (1+\varepsilon/\tan\beta_I)(dC_{Psi}/dx)\,dx = P_S/\left((\rho/2)\pi R^2 V^3\right) \quad (11)$$

$$(C_{PS})_{CR} = (C_{Ps})_{fwd} + (R_{aft}/R_{fwd})^2\ (C_{Ps})_{aft} \quad (12)$$

Propulsive Efficiency:

$$(\eta_{D_e})_{CR} = (1-t)\ C_{Ts}/C_{Ps} = P_E/P_D \quad (13)$$

where based on ship speed

$$(C_{Ts})_{DESIGN} = T/\left((\rho/2)\pi R^2 V^2\right)$$

$$(C_{Ps})_{DESIGN} = P_S/\left((\rho/2)\pi R^2 V^3\right)$$

fwd,aft = subscripts for forward and aft propellers, respectively

CR = subscript for the set of contrarotating propellers

C_{TSi} = nondimensional inviscid local thrust loading coefficient, $4ZG(x/\lambda_S - U_A/2V)$

C_{PSi} = nondimensional inviscid local power loading coefficient, $(4Z/\lambda_S)\times G\left((1-w_x)+U_T/2V\right)$

G = nondimensional circulation from lifting line theory

$U_A/2V$ = axial induced velocity from lifting line theory

$U_T/2V$ = tangential induced velocity from lifting line theory

V = ship speed

ρ = density of fluid

The calculated thrust (T) is obtained from Equation (9) and the shaft power (P_S) is calculated using Equation (11) for each propeller.

Other parameters useful in designing and evauating the performance of propellers include the advance coefficient (J), ship speed advance coefficient (J_V), thrust coefficient (K_T), torque coefficient (K_Q), moment due to thrust (M_{Tb}), moment due to torque (M_{Qb}), moment parallel to section nose-tail line (M_{xo}), moment perpendicular to the nose-tail line (M_{yo}), and the blade loading distribution (LI). These parameters are calculated as follows:

Advance Coefficient:

$$J=V(1-w_T)/(nD)=V_A/(nD) \tag{14}$$

Ship Speed Advance Coefficient:

$$J_V=V/(nD) \tag{15}$$

Thrust Coefficient:

$$K_T=T/(\rho n^2D^4)=(\pi C_{TS}/8)J_V{}^2 \tag{16}$$

Torque Coefficient:

$$K_Q=Q/(\rho n^2D^5)=(C_{PS}/16)J_V{}^3 \tag{17}$$

Moment Due to Thrust:

$$M_{Tb}(x)=\left(\rho\pi R^3V^2/(2Z)\right)\int_{x_h}^{1}(x-x_o)(1-\varepsilon\tan\beta_I)\left(dC_{TSi}/dx\right)dx \tag{18}$$

Moment Due to Torque:

$$M_{Qb}(x)=\left(\rho\pi R^3 V^2/(2Z)\right)\int_{x_h}^{1}(x-x_o)(\tan\beta_I+\varepsilon)\left(dC_{TSi}/dx\right)dx \qquad (19)$$

Moments Parallel to Section Nose-tail Line:

$$M_{xo}(x)=M_{Tb}\cos\phi+M_{Qb}\sin\phi \qquad (20)$$

Moment Perpendicular to Section Nose-tail Line:

$$M_{yo}(x)=M_{Tb}\sin\phi-M_{Qb}\cos\phi \qquad (21)$$

Blade Loading Distribution:

$$LI(x)=\tfrac{1}{2}\rho c V_r^{\,2}\, C_L \qquad (22)$$

where x, x_o = propeller nondimensional radial stations, r/R and r_o/R

ϕ = propeller pitch angle ($\phi=\beta_I$ in computer program)

V_r = section inflow velocity, $\sqrt{\left[(1-w_x)+U_A/2V\right]^2+\left[(x/\lambda_S)-U_T/2V\right]^2}$

PROPELLER STRESS CALCULATIONS USING BEAM THEORY

A propeller blade must contain enough material to keep the stresses within a blade below a certain predetermined level. This level depends on the material properties with regard to both steady-state and fatigue strength and to both mean and unsteady blade loading. The material selection controls the allowable stress level and the blade chord, thickness, rake and skew are the main parameters which control the blade stress for a given blade loading. Stresses based on beam theory[10] in the propeller blade are computed for each propeller. Both hydrodynamic and centrifugal loadings

are considered. Effects of rake and skew are included. In this stress calculation procedure, the propeller blade is represented as a straight cantilever beam of variable cross-section without camber. Experimental results show that the neutral axis of an airfoil section lies approximately along the mean line, so camber is not considered in the stress calculations presented. Only the maximum principal stresses calculated at the mid-chord of each section are printed as output in the computer program. Stresses for the final design should be calculated by finite element techniques if rake and skew for the propeller differ from usual propeller shapes.

PARAMETERS FOR MAKING BLADE SURFACE CAVITATION CHECKS

Brockett's theoretically derived incipient cavitation charts of Reference 13 can be used to predict the blade surface cavitation characteristics of each propeller once the lifting-line calculations have been completed. The two-dimensional camber-to-chord ratio (f_M/c), ideal angle of attack in degrees (α_i), section cavitation number (σ) nondimensionalized with the section inflow velocity (V_r), and the maximum and minimum fluctuating angles of attack ($\alpha_{max}, \alpha_{min}$) in degrees are parameters that must be determined before Brockett's incipient cavitation charts can be used.

These parameters are calculated as follows:

Section Maximum Camber to Chord Ratio for NACA a=0.8 Meanline:

$$f_M/c = 0.0679C_L \tag{23}$$

Section Ideal Angle of Attack in Degrees for NACA a=0.8 Meanline:

$$\alpha_i = 1.54\ C_L \tag{24}$$

Section Cavitation Number:

$$\sigma = 2g(H-xR)/V_r^2 \tag{25}$$

where g = acceleration due to gravity

H = static head at shaft centerline (see section on Static Head)

V_r = inflow velocity of each propeller section.

The maximum and minimum fluctuating angles of attack (α_{max}, α_{min}) in degrees are calculated using the method derived by Lerbs and Rader in Reference 18. These calculations can be made using the following equations:

Maximum Fluctuating Angles of Attack:

$$\alpha_{max} = \alpha_i - (-\Delta\beta)F(x) \tag{26}$$

Minimum Fluctuating Angles of Attack:

$$\alpha_{min} = \alpha_i - (+\Delta\beta)F(x) \tag{27}$$

where $-\Delta\beta$ = maximum effective angle of attack in degrees (from wake survey data)

$+\Delta\beta$ minimum effective angle of attack in degrees (from wake survey data)

18. Lerbs, H.W. and Rader, H.P., "Uber der Auftriebsgradienten von Profilen im Propeller Verband," Schiffstechnik, Vol. 9, No. 48, p 178-180, 1962

The parameter $F(x)$ in Equations (26) and (27) is dependent on the hydrodynamic flow angle (β_I), the advance angle (β) and the lift coefficient (C_L), and is calculated on the computer using the following equation:

$$F(x) = 1/\left(1+2\pi\tan(\beta_I-\beta)/C_L\right) \tag{28}$$

The Burrill Cavitation Charts[12] can also be used to give an approximate check on the cavitation performance of propellers. Burrill's thrust loading coefficient (τ_c) and cavitation number ($\sigma_{0.7}$) at 0.7 radius, defined as follows, are parameters that must be known in order to use these cavitation charts:

Burrill Loading Coefficient:

$$\tau_c = T/\left\{(\rho/2)A_p\left(V(1-w_{x=0.7})\right)^2+(0.7\pi nD)^2\right\} \tag{29}$$

Burrill Cavitation Number at 0.7 Radius:

$$\sigma_{0.7} = 2gH/\left\{\left(V(1-w_{x=0.7})\right)^2+(0.7\pi nD)^2\right\} \tag{30}$$

where A_E = propeller expanded area, $Z\int_{r_h}^{R} c\,dr$

A_O = propeller disc area, $\pi D^2/4$

A_P = propeller projected area, $\left(1.067 - 0.229(P/D)_i\right)A_E$

$(P/D)_i$ = estimated propeller pitch ratio at 0.7 radius, estimated as $0.7\pi\tan\beta_I$

Keller's method[11] of predicting the minimum expanded area ratio of the propeller is also calculated on the computer.

The minimum expanded area ratio, based on eliminating back bubble type cavitation, is computed as follows:

$$(A_E/A_O)_K = (2.6 + 0.6Z)K_T/\{\sigma_{0.7}(J^2 + (0.7\pi)^2)\} + K \quad (31)$$

where K = 0.2 is used for single screw ships with manganese-bronze propellers having rake of approximately 10 degrees, K = 0.10 is used for twin-screw ships with copper-aluminum-bronze propellers, K = 0.15 is used for twin-screw ships with manganese-bronze propellers, and K = 0 to K - 0.05 is used for propellers for fast ships such as destroyers and frigates. The constant, K = 0.15, was used in developing this computer program. If a different value of K is desired, the expanded area ratio calculated in Equation (31) should be adjusted to account for changes in the value of K.

Chord Lengths for Lifting Surface Pitch and Camber Calculations

The final pitch and camber for each propeller can be calculated using Nelson's computer program, presented in Reference 4, based on lifting surface theory for contrarotating propellers. However, Nelson has shown that in some cases lifting-surface interaction effects of contrarotating propellers are small. If this is the case, single propeller lifting surface theory from References 19, 20, 21, and

19. Kerwin, J.E., "The Solution of Propeller Lifting-Surface Problems by Vortex Lattice Methods," Department of Naval Architecture and Marine Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts, 1961
20. Kerwin, J.E. and Leopold, R., "Propeller Incidence Correction Due to Blade Thickness," Journal of Ship Research, Vol. 7, No. 2, 1963, p 1, 6
21. Cheng, H.M., "Hydrodynamic Aspects of Propeller Design Based On Lifting-Surface Theory: Part I - Uniform Chordwise Load Distribution," David Taylor Model Basin Report 1802, 1964

22 can be used to calculate the final pitch and camber for each propeller. These programs require as input the section chord length, $(c/R)_{LE}$ and $(c/R)_{TE}$ nondimensionalized on propeller radius, in terms of the skew angle (θ_S), hydrodynamic flow angle (β_I) and blade outline (c/D). The parameter $(c/R)_{LE}$ and $(c/R)_{TE}$ measured from the leading and trailing edges to its reference line, respectively, are calculated in the following manner on the computer:

Chord Lengths Measured from Blade Leading Edge:

$$(c/R)_{LE} = x\theta_s/(57.296 \cos\beta_I) - c/D \tag{32}$$

Chord Lengths Measured from Blade Trailing Edge:

$$(c/R)_{TE} = x\theta_s/(57.296 \cos\beta_I) + c/D \tag{33}$$

SPACING BETWEEN BLADES AND FILLETS

Propeller designs should have enough clearance between blades at the hub so fillets can be properly applied. Hill[23] derived the following equation which is used in the program to estimate spacing between blades G_Z at the hub without fillets:

$$G_Z = (2\pi r_h)/Z - (t_h/\sin\phi) \tag{34}$$

where ϕ is the propeller pitch angle ($\phi = \beta_I$ in computer program). Based on a number of full-scale propellers built with standard fillets, Hill's blade clearance equation was modified the following manner to estimate spacing G_F between fillets

22. Cheng, H.M., "Hydrodynamic Aspects of Propeller Design Based On Lifting-Surface Theory: Part II - Arbitrary Chordwise Load Distribution," David Taylor Model Basin report 1803, 1965
23. Hill, J.G., "The Design of Propellers," Transactions of the Society of Naval Architects and Marine engineers, Vol. 57, 1949

at the hub during the preliminary stage of the design.

$$G_F = (2\pi r_h)/Z - (1.9t_h/\sin\phi) \tag{35}$$

A layout of blade sections is recommended as a final fillet clearance check.

PROPELLER WEIGHT AND CENTER OF GRAVITY

The approximate propeller weight (W_p) and location of center of gravity (CG) from the propeller center line is also calculated for each design. In order to make these calculations, the specific weight of the material (ρ_p) must be specified as input. The propeller hub is assumed to be a circular cylinder of equal length and diameter. The propeller center line is located at the mid length of the propeller hub and no allowance is made for the propeller bore or blade root fillets in these calculations. The weight (W_p) for each propeller is calculated as follows:

Propeller Weight:

$$W_P = W_B + W_H \tag{36}$$

where W_B = weight of blades, $\rho_p Z \int_{x_h}^{1} a(x)dx$

W_H = weight of hub, $\pi/4(\rho_p D_H)$

D_H = hub diameter

$a(x)$ = area of section at radius x, $2c(x)t(x)\int_0^1 t(x,x_\ell)\, dx$

$c(x)$ = chord length of section at radius x

$t(x)$ = maximum thickness of section thickness

$t(x,x_\ell)$ = chordwise distribution of section thickness (NACA 66 modified thickness form is used in program)

x_ℓ = nondimensional coordinate along the section chord (r_ℓ/c)

ρ_p = specific weight of material considered

The propeller center of gravity (CG) with respect to the blade center line, where plus values represent the distance ahead of the center line and negative values aft of the center line, is calculated in the following manner:

Center of Gravity:

$$CG = M_p/M_p \tag{37}$$

where M_p = moment of the propeller, $\rho_m \, Z\int_{x_h}^{1} a(x)\, B(x)\, dx$

$B(x)$ = distance of center of gravity from propeller center line, $\bar{y}\cos\phi + \bar{x}\sin\phi - \theta_s\, x\, R\tan\phi - \theta_R\, x + d_H/2$

$\bar{x}$ = longitudinal center of gravity along chord line

$\bar{y}$ = vertical center of gravity perpendicular to chord line

θ_R = rake angle in radians

θ_s = skew angle in radians

ϕ = pitch angle in radians, ($\phi = \beta_I$ is used in the program)

COMPUTER PROGRAM

A new computer program has been derived for the preliminary design of contrarotating propellers using the CDC 6400, 6600 and 6700 computers at DTNSRDC. A core storage of approximately

128,000 octal is required for the computer program, and it takes approximately 4 minutes to compile the computer program. The actual running time per case using the design thrust option is approximately 6 minutes and when the design shaft horsepower option is used, the running time is approximately 9 minutes. A detailed description of the input and output formats for the computer program is presented in Appendix A, and a FORTRAN listing of the new computer program is shown in Appendix B.

PROPELLER DESIGN THRUST AND POWER OPTIONS

The thrust option can be used to make lifting line calculations for propellers required to produce a given thrust at specified values of speed and rpm (this is accomplished by adjusting the input $\tan\beta_I$ distribution), or the power option can be used if the propeller is required to absorb a specified power at a given rpm (in which case the speed is determined).

From each calculated power, a new value of speed (assumed to vary as the cube root of the ratio of the design and calculated power) is obtained and its corresponding effective power is obtained from the effective power input curve. Design calculations again produce a new calculated power, and the process continues until the closeness criteria of design and calculated power is satisfied (two iterations are normally sufficient). Smaller increments of input speeds in general cause faster convergence.

Once the basic shape of the distribution is defined (see the Hydrodynamic Flow Angle Distribution section) the final $\tan\beta_I$ distribution $K_4 \tan\beta_I$ is determined using the thrust or power options, by making lifting line calculations of three nondimensional thrust loading coefficients $(C_{Ts})_1$, $(C_{Ts})_2$, and $(C_{Ts})_3$ that correspond to three hydrodynamic pitch distributions, $K_1 \tan\beta_I$, $K_2 \tan\beta_I$, and $K_3 \tan\beta_I$ where $K_1 = 0.975$, $K_2 = 1.0$, and $K_3 = 1.025$. Once these calculations are obtained, the following system of equations are set up:

$$(C_{Ts})_1 = A + BK_1 + CK_1^2$$

$$(C_{Ts})_2 = A + BK_2 + CK_2^2$$

$$(C_{Ts})_3 = A + BK_3 + CK_3^2$$

from which values of A, B, and C are obtained. Then, values of A, B, and C are substituted in the following equation to obtain the value of K_4.

$$C_{Ts} = A + BK_4 + CK_4^2$$

where C_{Ts} = design thrust loading coefficient (Equation 9).

DESIGN CALCULATIONS OF A SAMPLE SET OF CONTRAROTATING PROPELLERS

Design calculations are shown in Table 1 for a sample set of contrarotating propellers with 7 blades and an expanded area ratio (A_E/A_O) of 0.293 for the forward propeller, and 6 blades with A_E/A_O = 0.365 for the aft propeller. These propellers were designed to operate in a wake with a thrust loading coefficient based on ship speed (C_{Ts}) of 0.265 and an advance coefficient (J) of 1.235. Both propellers had a 100 percent linear skew distribution resulting in 51.4

and 60 degree blade tip skew angles for the forward and aft propellers, respectively. Solid and dashed lines in Figures 2 through 8 show calculations obtained using the old design method[1,2,3] and the new computer program, respectively. These figures show that the radial distribution of the hydrodynamic pitch ($\pi x \tan\beta_I$), nondimensional circulation (G), axial ($U_T/2V$) and tangential ($U_T/2V$) induced velocities calculated using both methods differed significantly, especially for the aft propeller. The thrust loading coefficient (C_{Ts}), power loading coefficient (C_{Ps}) and propulsive efficiency (η_D) calculated for the sample set of contra-rotating propellers using the old and new methods are printed in Table 2. Results in Table 2 show that the old design method predicts similar thrust (C_{Ts}) and power (C_{Ps}) loading coefficients for the forward and aft propellers where as the new design method predicts that the aft propeller C_{Ts} and C_{Ps} values are significantly higher than those calculated for the forward propeller. The propulsive efficiency (η_D) of 0.886 predicted for the sample set of contrarotating propellers using the new method is approximately 2 percentage points lower than the η_D value of 0.912 calculated using the old design method. Performance predictions using the new design method should be more accurate than the predictions made using the old design method because of the improved methods of accounting for the propeller interaction effects.

RECOMMENDATIONS

The following investigations should be carried out in the future in order to better design and predict the performance of contrarotating propellers:

1. Utilize induced velocities derived by Kerwin in Reference 8 to obtain more exact calculations for contraction of the slip stream and the aft propeller diameter. This subroutine should be reprogrammed to significantly reduce the running time presently required to make it practical for use in the contrarotating propeller design computer program.
2. Include the effects of the hull radial induced velocity as an input option in the contrarotating propeller design procedure.
3. Conduct model propulsive and cavitation experiments on a set of contrarotating propellers to validate the design procedure.
4. Options for specifying noncylindrical hubs, arbitrary propeller locations and allowances for the propeller bore should be added to the program presented to improve the predictions of propeller weight and center of gravity.

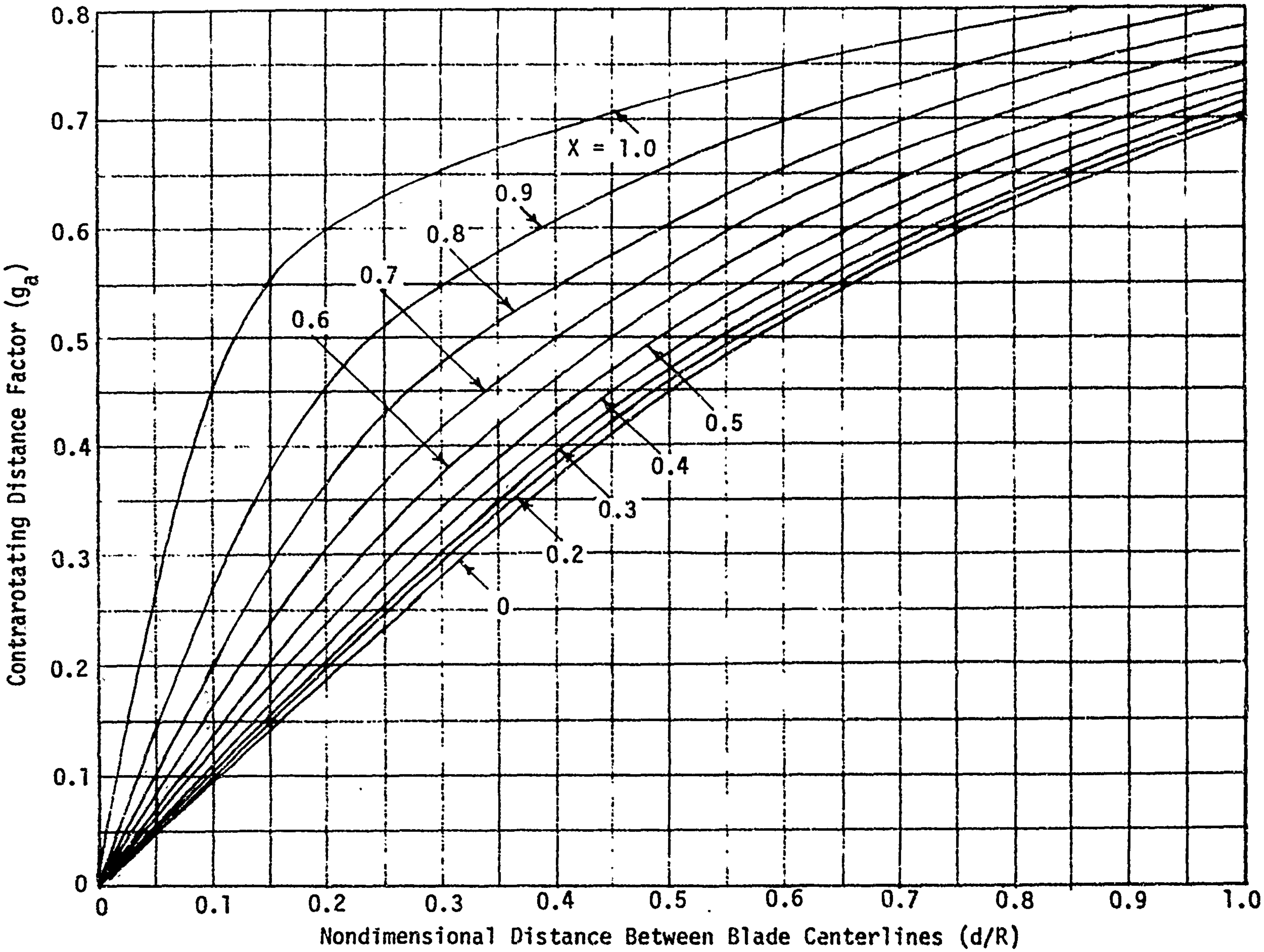

Figure 1 - Lerbs Distance Factors (g_a) for Aft Propeller Diameter Calculations

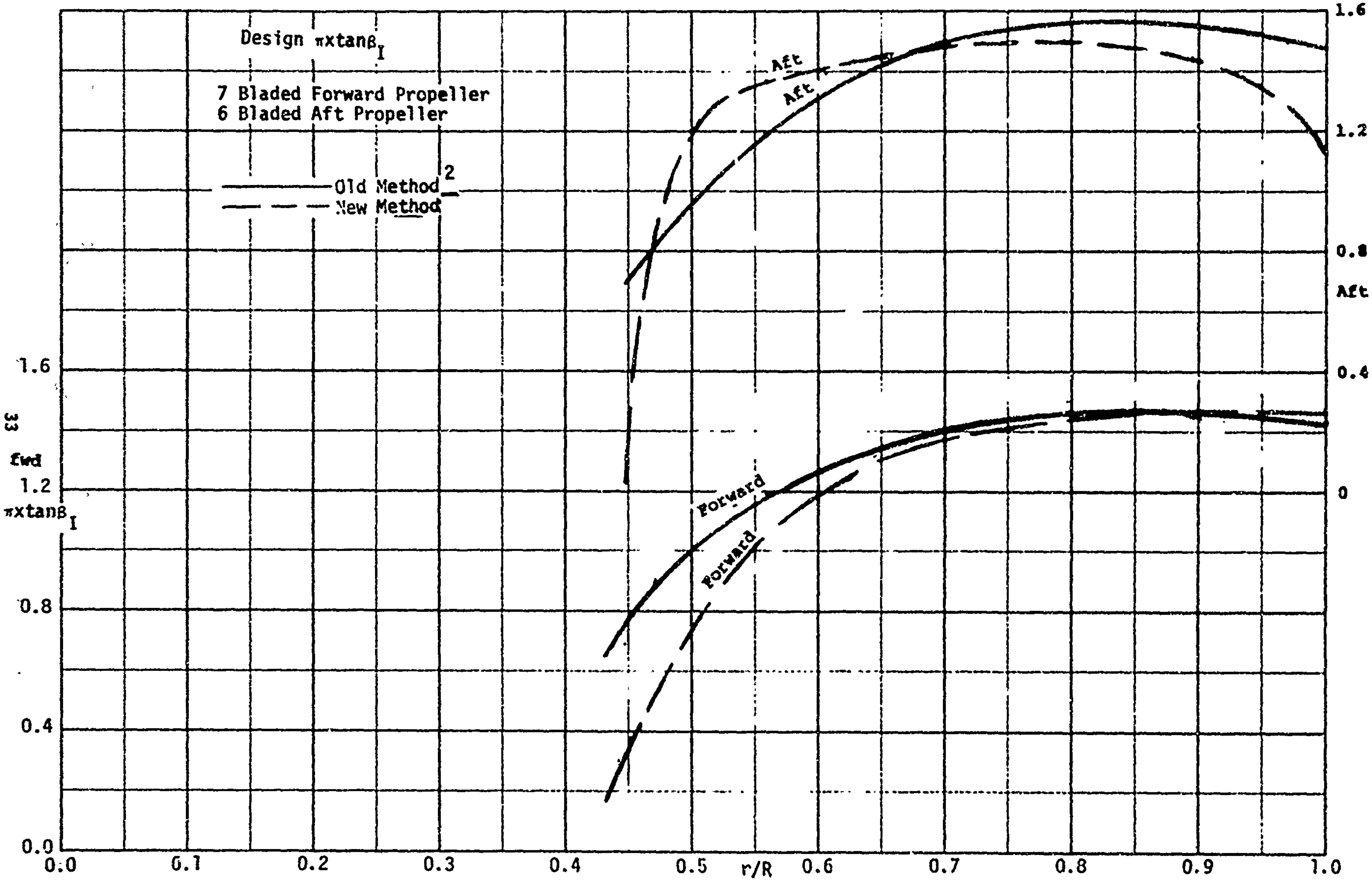

Figure 2 - Hydrodynamic Pitch Angle Distribution for Sample Set of Propellers

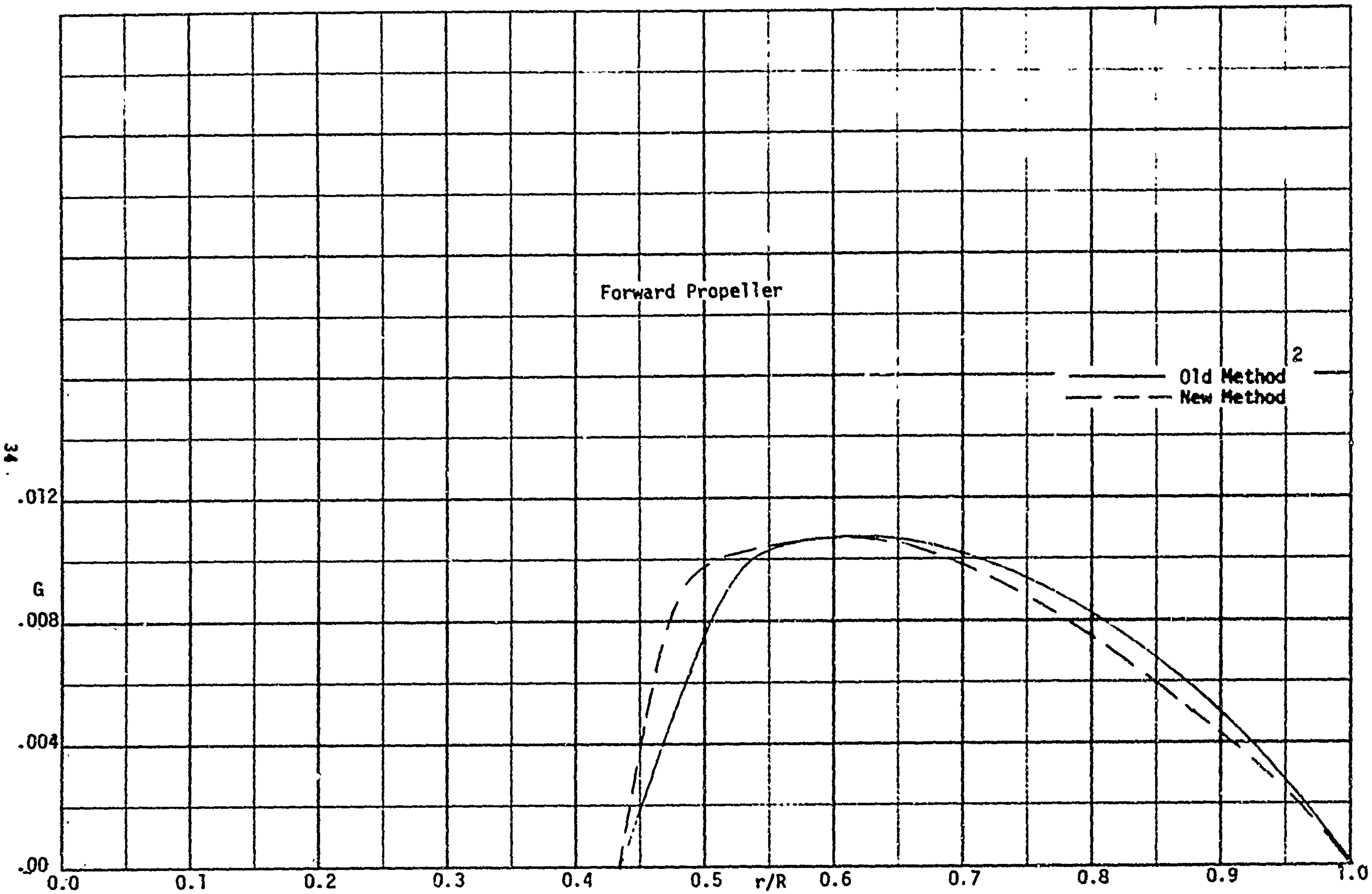

Figure 3 - Circulation Distributions Calculated for the Forward Propeller

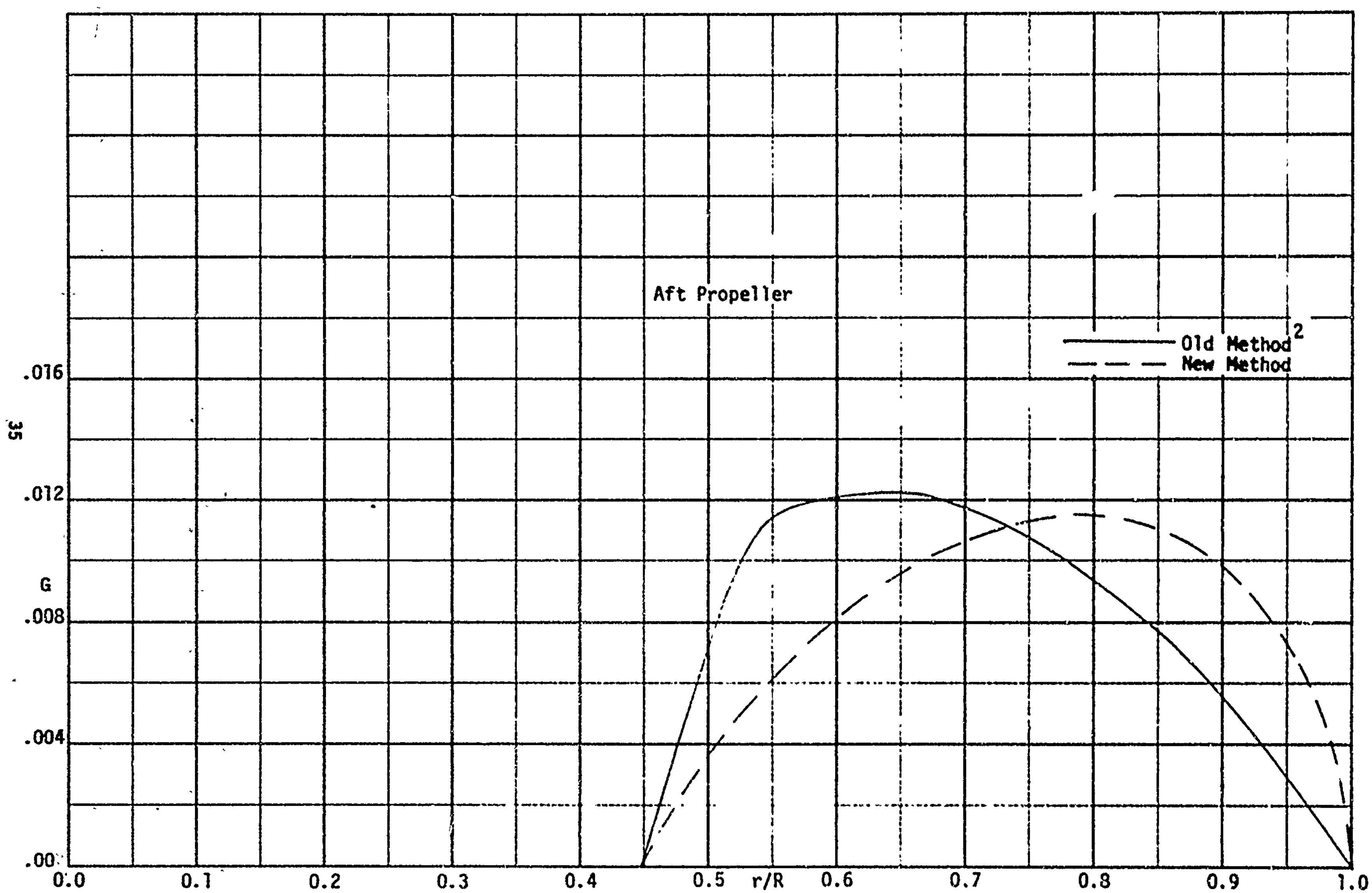

Figure 4 - Circulation Distributions Calculated for the Aft Propeller

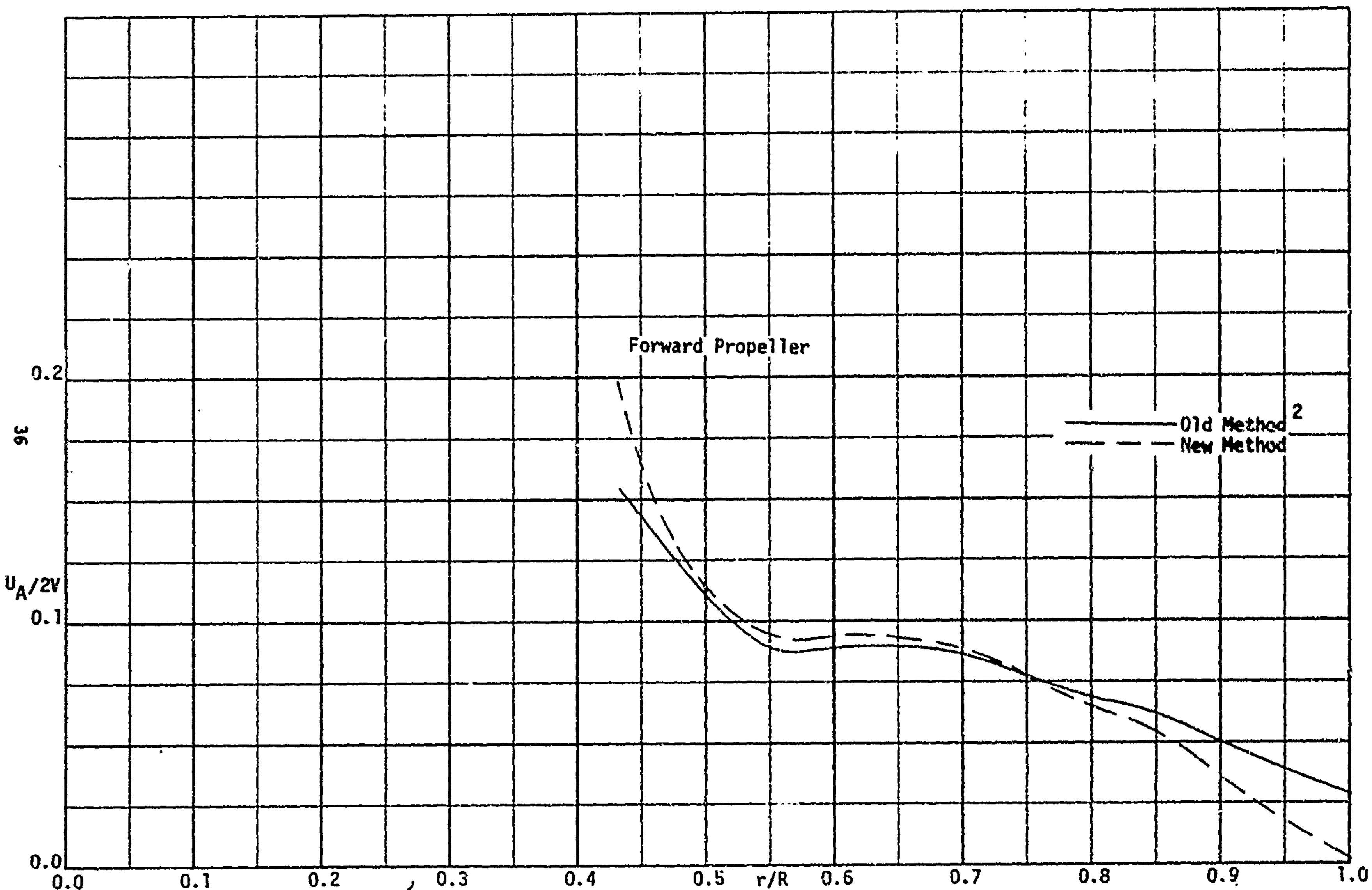

FIGURE 5 - Axial Induced Velocities Calculated for the Forward Propeller

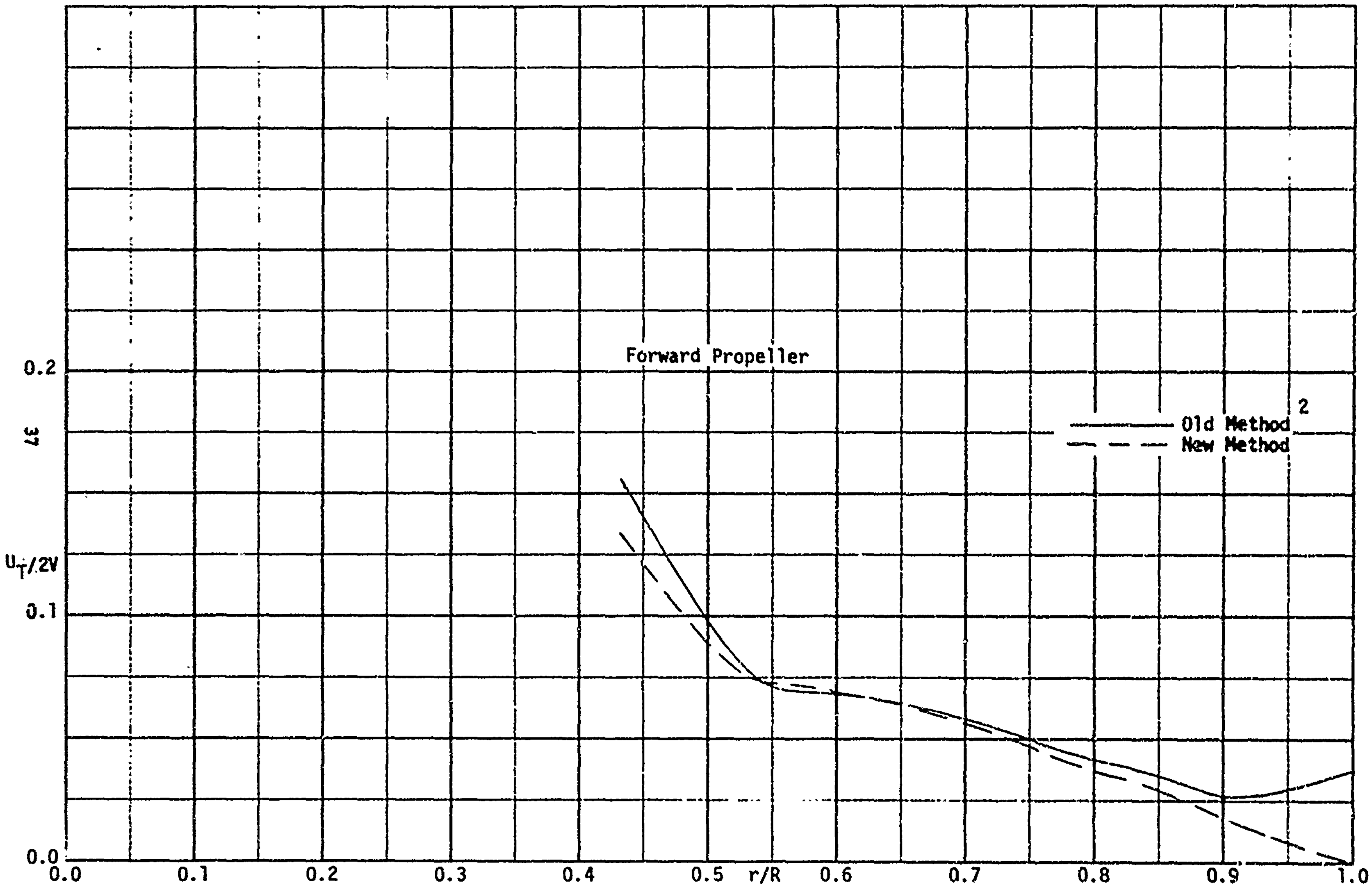

FIGURE 6 - Tangential Induced Velocities Calculated for the Forward Propeller

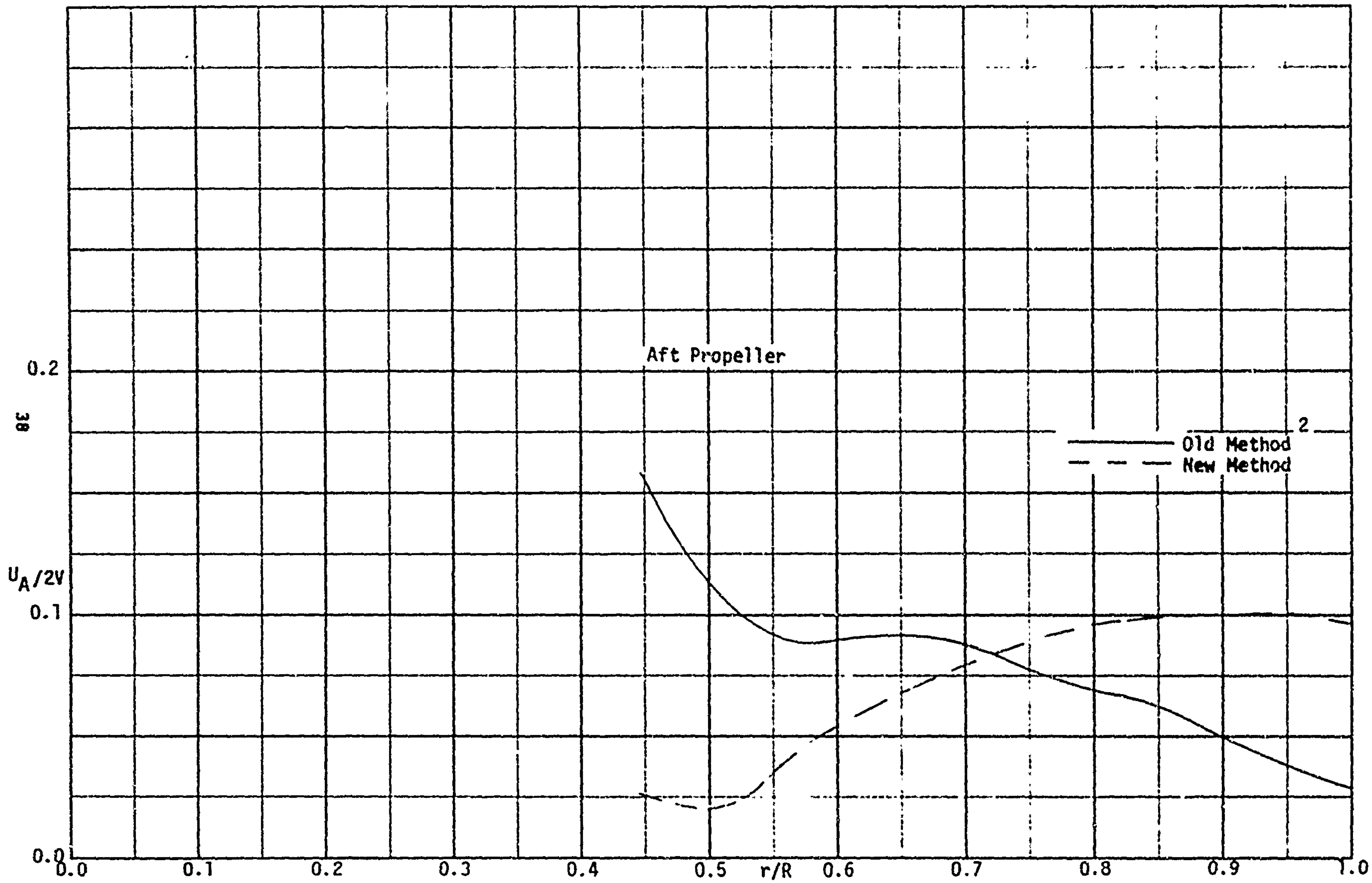

FIGURE 7 - Axial Induced Velocities Calculated for the Aft Propeller

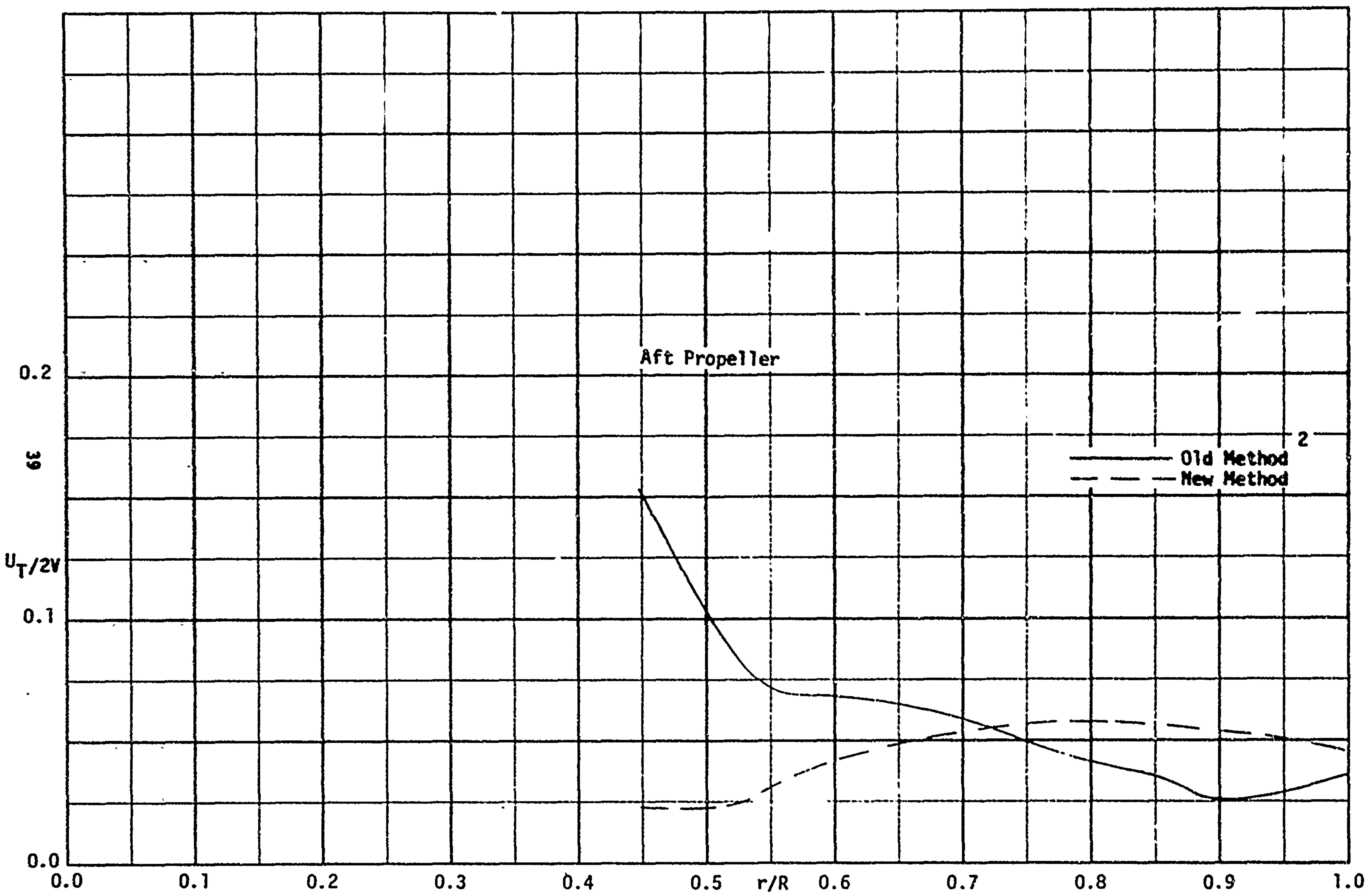

FIGURE 8 - Tangential Induced Velocities Calculated for the Aft Propeller

TABLE 1

OUTPUT DATA FOR THE SAMPLE SET OF CONTRAROTATING PROPELLERS

```
      FWD
THRUST OPTION
NO OF V=  1.0     DENSITY OF PROP(KG/M3)=    8303.97
V(M/SEC)=   1.2450E+01
PE(KW)=     1.2040E+01
D(M)=    .3911     1-WTT=    .7050     1-THD=    .7640     H(M)=   19.4000     RHO(KG/M3)= 1025.8600
TETS OPT=  1.000    RAKE OPT=  0.000
TANBI OPT= 1.00     DRAG OPT=    .0085    TANB OPT= 0.00
Z=            7.0000E+00
AE/A0=        2.9300E-01
N(REV/MIN)=   1.0900E+03

X=        4.3300E-01  5.0800E-01  5.5000E-01  6.0000E-01  6.5000E-01  7.0000E-01  8.0000E-01  8.5000E-01  9.0000E-01
          9.5000E-01  1.0000E+00
1-WX=     1.4000E-01  3.6300E-01  4.7050E-01  5.4170E-01  5.9360E-01  6.4190E-01  7.1760E-01  7.4200E-01  7.7210E-01
          7.9500E-01  8.1310E-01
TANBI=    1.2500E-02  4.7100E-01  5.7300E-01  6.1500E-01  6.2590E-01  6.1110E-01  5.6080E-01  5.3380E-01  3.0673E-01
          4.7590E-01  4.5460E-01
C/D=      1.4140E-01  1.4140E-01  1.4140E-01  1.4140E-01  1.4140E-01  1.4140E-01  1.3820E-01  1.2930E-01  1.1760E-01
          9.3000E-02  0.
T/C=      1.9400E-01  1.7610E-01  1.6470E-01  1.5420E-01  1.4360E-01  1.3300E-01  1.1430E-01  1.1090E-01  1.0800E-01
          1.2040E-01  0.

 D(M)=3.9115E-01    N(REV/MIN)=1.0900E+03    Z=7.0000E+00    AE/A0=2.9300E-01
 CPTI=8.7993E-02    CPSI=1.0193E-01    CTSI=1.3506E-01    CTSI/CPSI=1.3250E+00
```

X	TANBI	TAN B	G	UT/2V	UA/2V	DCTSI	DCPSI	VR(M/SEC)	CAVV
4.3300E-01	1.2517E-01	2.3117E-01	0.	-7.3861E-03	-6.1432E-02	0.	0.	7.6951E+00	6.3839E+00
5.0000E-01	4.8295E-01	4.3613E-01	4.8390E-03	2.9550E-02	2.4695E-02	1.0877E-01	4.3722E-02	1.1100E+01	2.9642E+00
5.5000E-01	5.9753E-01	4.9375E-01	7.2712E-03	4.6221E-02	5.6593E-02	1.8265E-01	1.0124E-01	1.2956E+01	2.2052E+00
6.0000E-01	6.3060E-01	5.1539E-01	9.0568E-03	5.9913E-02	8.0045E-02	2.5003E-01	1.6476E-01	1.4514E+01	1.7723E+00
6.5000E-01	6.4177E-01	5.1913E-01	1.0159E-02	6.7168E-02	9.7133E-02	3.0615E-01	2.2466E-01	1.5924E+01	1.4805E+00
7.0000E-01	6.2660E-01	5.1716E-01	1.0310E-02	6.3032E-02	9.6226E-02	3.4010E-01	2.6451E-01	1.7311E+01	1.2558E+00
8.0000E-01	5.7502E-01	5.0031E-01	8.8782E-03	4.6832E-02	9.3225E-02	3.4491E-01	2.8447E-01	1.9328E+01	9.4939E-01
8.5000E-01	5.4734E-01	4.9503E-01	7.6439E-03	4.0317E-02	7.3255E-02	3.1879E-01	2.6693E-01	2.1143E+01	8.4323E-01
9.0000E-01	5.1955E-01	4.7498E-01	5.9235E-03	2.9500E-02	5.7069E-02	2.6470E-01	2.2355E-01	2.2394E+01	7.5147E-01
9.5000E-01	4.9105E-01	4.6200E-01	3.8433E-03	1.9748E-02	4.3295E-02	1.8305E-01	1.5467E-01	2.3596E+01	6.7648E-01
1.0000E+00	4.6613E-01	4.4781E-01	0.	1.2728E-02	2.7330E-02	0.	0.	2.4769E+01	6.1360E-01

CPT=8.6254E-02   CPS=1.0827E-01   CTS=1.3246E-01   CTS/CPS=1.2734E+00

X	CL	ALI(DEG)	FM/C	CD/CL	F(X)	LI(N/M)	TETS(DEG)	(C/RO)LE	(C/RO)TE	T/RO
4.330E-01	0.	0.	0.	0.	0.	0.	0.	-1.414E-01	1.414E-01	5.486E-02
5.000E-01	2.412E-01	3.714E-01	1.638E-02	3.524E-02	4.982E-01	8.431E+02	6.077E+00	-8.251E-02	2.003E-01	4.950E-02
5.500E-01	3.105E-01	4.782E-01	2.108E-02	2.737E-02	4.185E-01	1.479E+03	1.061E+01	-2.325E-02	2.596E-01	4.658E-02
6.000E-01	3.453E-01	5.317E-01	2.344E-02	2.462E-02	3.939E-01	2.063E+03	1.515E+01	4.613E-02	3.289E-01	4.361E-02
6.500E-01	3.530E-01	5.436E-01	2.397E-02	2.408E-02	3.791E-01	2.539E+03	1.968E+01	1.233E-01	4.067E-01	4.061E-02
7.600E-01	3.293E-01	5.075E-01	2.238E-02	2.579E-02	3.352E-01	2.801E+03	2.422E+01	2.073E-01	4.906E-01	3.761E-02
8.000E-01	2.522E-01	3.884E-01	1.712E-02	3.370E-02	4.039E-01	2.777E+03	3.329E+01	3.980E-01	6.744E-01	3.159E-02
8.500E-01	2.193E-01	3.377E-01	1.489E-02	3.877E-02	4.149E-01	2.537E+03	3.782E+01	5.107E-01	7.637E-01	2.861E-02
9.000E-01	1.760E-01	2.710E-01	1.195E-02	4.830E-02	4.333E-01	2.082E+03	4.236E+01	6.322E-01	8.674E-01	2.540E-02
9.500E-01	1.370E-01	2.110E-01	9.303E-03	6.204E-02	4.795E-01	1.423E+03	4.689E+01	7.772E-01	9.592E-01	2.239E-02
1.000E+00	0.	0.	0.	0.	0.	0.	5.143E+01	9.933E-01	9.933E-01	0.

```
ETAD=9.3467E-01  PS(KW)=1.7275E+01   1-THD=7.6400E-01   1-WTT=7.0500E-01   V(KNOTS)=2.4204E+01      DESIGN TH(N)=1.2658E+03
                                                                           V(M/SEC)=1.2451E+01  CALCULATED TH(N)=1.2658E+03
```

TABLE 1 CONTINUED

X	AREA(M2)	XBAR(M)	YBAR(M)	IXO(M4)	IYO(M4)	MXO(N-M)	MYO(N-M)	MTB(N-M)	MQD(N-M)	MAXSTRESS(PA)
4.330E-01	4.268E-04	2.813E-02	0.	2.896E-09	5.750E-08	1.162E+01	3.504E+01	1.085E+01	6.711E+00	3.357E+07
5.500E-01	3.624E-04	2.813E-02	0.	1.772E-09	4.881E-08	7.703E+00	5.707E+01	6.817E+00	4.182E+00	3.146E+07
6.000E-01	3.393E-04	2.813E-02	0.	1.454E-09	4.570E-08	6.025E+00	3.368E+01	5.263E+00	3.203E+00	2.772E+07
6.500E-01	3.160E-04	2.813E-02	0.	1.175E-09	4.256E-08	4.463E+00	2.529E+01	3.869E+00	2.329E+00	2.346E+07
7.000E-01	2.926E-04	2.813E-02	0.	9.332E-10	3.942E-08	3.136E+00	1.842E+01	2.707E+00	1.611E+00	1.929E+07
8.000E-01	2.402E-04	2.750E-02	0.	5.605E-10	3.091E-08	1.133E+00	6.525E+00	9.812E-01	5.703E-01	1.032E+07
8.500E-01	2.031E-04	2.567E-02	0.	3.748E-10	2.277E-08	5.403E-01	3.029E+00	4.684E-01	2.693E-01	6.497E+06

X	RAKE	PI XTANBI	PI XTANB
4.330E-01	0.	1.744E-01	2.145E-01
5.000E-01	0.	7.586E-01	6.851E-01
5.500E-01	0.	1.015E+00	8.618E-01
6.000E-01	0.	1.189E+00	9.771E-01
6.500E-01	0.	1.311E+00	1.060E+00
7.500E-01	0.	1.379E+00	1.137E+00
8.000E-01	0.	1.445E+00	1.257E+00
8.500E-01	0.	1.462E+00	1.295E+00
9.000E-01	0.	1.463E+00	1.343E+00
9.500E-01	0.	1.465E+00	1.379E+00
1.000E+00	0.	1.464E+00	1.407E+00

WEIGHT OF BLADES(N)= 16.9261

WEIGHT OF PROP(BLADES+CYLINDRICAL HUB)(N)= 327.6586

CENTER OF GRAVITY OF PROP REFERENCED FROM MIDCHORD OF ROOT SECTION (- FWD, + AFT)/D= .083728

CENTER OF GRAVITY OF BLADES REFERENCED FROM MIDCHORD OF ROOT SECTION (- FWD, + AFT)/D= .072175

HUB DIMENSIONS/D
HUB DIAM = .433898
HUB LENGTH = .4338
MIDCHORD OF ROOT SECTION TO AFT END OF HUB = .2165

KELLERS MINIMUM EAR= .2953E+00

SPEED COEFF V/(ND) JS= .1752E+01

ADVANCE COEFF V(1-WTT)/(ND) JA= .1235E+01

DESIGN THRUST COEFF KT= .1597E+00

TORQUE COEFF KQ= .3641E-01

PROPULSIVE EFFICIENCY ETAD= .9347E+00

BURRILL THRUST COEFF TC= .2782E+00

BURRILL CAVITATION COEFF SIGMA(0.7)= .1175E+01

CLEARANCE AT HUB BETWEEN BLADES/D= -.00272637

CLEARANCE AT HUB BETWEEN FILLETS/D= -.02741481

TABLE 1 CONTINUED

AFT PROP OF CONTRAROTATING SET

```
      AFT
THRUST OPTION
NO OF V=  1.0      DENSITY OF PROP(KG/M3)=    8303.97
V(M/SEC)=  1.2450E+01
PE(KW)=     1.2040E+01
D(M)=    .3792     1-WTT=    .7050     1-THD=    .7640      H(M)=  19.4000     RHO(KG/M3)= 1025.8600
TETS OPT=  1.000    RAKE OPT=   0.000
TANBI CPT= 1.00     DRAC OPT=    .0085     TANB OPT= 0.00
Z=             6.0000E+00
AE/A0=         3.6500E-01
N(REV/MIN)=    1.0900E+03

X=          4.4700E-01  5.1700E-01  5.6000E-01  6.0600E-01  6.5300E-01  7.0000E-01  7.9700E-01  8.4700E-01  8.9600E-01
            9.4700E-01  1.0000E+00
1-WX=       3.7700E-01  5.1500E-01  5.8300E-01  6.3400E-01  6.7300E-01  7.3400E-01  7.5300E-01  7.7500E-01  7.9400E-01
            8.0800E-01  8.1900E-01
TANBI=      3.0000E-02  9.2500E-01  9.0500E-01  8.5000E-01  8.2000E-01  7.8000E-01  6.9500E-01  6.4500E-01  5.9500E-01
            5.3000E-01  4.1000E-01
C/D=        1.6530E-01  1.6530E-01  1.6530E-01  1.6530E-01  1.6530E-01  1.6530E-01  1.6150E-01  1.5300E-01  1.3800E-01
            1.1100E-01  0.
T/C=        1.6100E-01  1.4300E-01  1.3900E-01  1.3100E-01  1.2200E-01  1.1500E-01  9.8080E-02  9.4000E-02  9.3000E-02
            1.0100E-01  0.

  D(M)=3.7922E-01    N(REV/MIN)=1.0900E+03   Z=6.0000E+00    AE/A0=3.6500E-01
  CPTI=9.9649E-02    CPSI=1.2073E-01    CTSI=1.4394E-01    CT ./CPSI=1.1922E+00
```

X	TANBI	TAN B	G	UT/2V	UA/2V	DCTSI	DCPSI	VR(M/SEC)	CAVV
4.4700E-01	2.5955E-02	4.2552E-01	0.	-5.1289E-02	-3.5277E-01	0.	0.	1.1674E+01	3.0458E+00
5.1700E-01	7.9720E-01	5.2576E-01	1.0766E-02	1.3126E-01	1.5975E-01	2.1669E-01	1.7045E-01	1.3478E+01	2.0711E+00
5.6000E-01	7.7397E-01	5.4787E-01	1.3311E-02	1.1992E-01	1.5345E-01	3.0164E-01	2.5036E-01	1.4910E+01	1.7007E+00
6.0600E-01	7.3256E-01	5.9131E-01	1.3235E-02	7.9048E-02	1.0735E-01	3.2131E-01	2.5671E-01	1.5614E+01	1.5493E+00
6.5300E-01	7.0671E-01	5.7233E-01	1.3080E-02	7.3499E-02	1.0607E-01	3.4607E-01	2.8758E-01	1.6830E+01	1.3399E+00
7.0000E-01	6.7224E-01	5.5726E-01	1.2526E-02	6.5723E-02	1.0117E-01	3.6002E-01	3.0575E-01	1.7965E+01	1.1725E+00
7.9700E-01	5.9899E-01	5.1606E-01	1.0308E-02	5.0914E-02	3.0497E-02	3.4337E-01	3.0447E-01	2.0039E+01	9.0629E-01
8.4700E-01	5.5599E-01	4.9316E-01	8.4429E-03	3.9737E-02	7.6455E-02	3.1039E-01	2.7114E-01	2.1321E+01	7.9420E-01
8.9600E-01	5.1279E-01	4.6995E-01	6.0972E-03	2.7276E-02	5.8335E-02	2.4324E-01	2.1074E-01	2.3260E+01	6.9849E-01
9.4700E-01	4.5678E-01	4.4419E-01	2.8496E-03	5.3906E-03	2.0436E-02	1.2404E-01	1.0306E-01	2.4827E+01	6.1344E-01
1.0000E+00	3.5335E-01	4.1762E-01	0.	-4.2195E-02	-1.1097E-01	0.	0.	2.6424E+01	5.4075E-01

CPT=9.7507E-02   CPS=1.2787E-01   CTS=1.4093E-01   CTS/CPS=1.1021E+00

X	CL	ALI(DEG)	FM/C	CD/CL	F(X)	LI(N/M)	TETS(DEG)	(C/RO)LE	(C/RO)TE	T/RO
4.470E-01	0.	0.	0.	0.	0.	0.	0.	-1.653E-01	1.653E-01	5.323E-02
5.170E-01	3.780E-01	5.822E-01	2.567E-02	2.248E-02	2.401E-01	2.208E+03	7.595E+00	-7.766E-02	2.529E-01	4.893E-02
5.600E-01	4.225E-01	6.507E-01	2.669E-02	2.012E-02	2.926E-01	3.020E+03	1.226E+01	-1.333E-02	3.173E-01	4.595E-02
6.060E-01	4.012E-01	6.173E-01	2.724E-02	2.119E-02	3.757E-01	3.145E+03	1.725E+01	6.308E-02	3.915E-01	4.331E-02
6.530E-01	3.693E-01	5.672E-01	2.501E-02	2.308E-02	3.739E-01	3.346E+03	2.235E+01	1.456E-01	4.772E-01	4.033E-02
7.000E-01	3.299E-01	5.081E-01	2.240E-02	2.576E-02	3.857E-01	3.425E+03	2.745E+01	2.388E-01	5.694E-01	3.602E-02
7.970E-01	2.443E-01	3.762E-01	1.659E-02	3.479E-02	3.804E-01	3.206E+03	3.797E+01	4.542E-01	7.772E-01	3.165E-02
8.470E-01	1.978E-01	3.047E-01	1.343E-02	4.296E-02	3.901E-01	2.804E+03	4.340E+01	5.810E-01	8.573E-01	2.375E-02
8.960E-01	1.436E-01	2.259E-01	1.009E-02	5.720E-02	4.066E-01	2.153E+03	4.572E+01	7.182E-01	9.942E-01	2.567E-02
9.470E-01	8.090E-02	1.246E-01	5.493E-03	1.051E-01	5.516E-01	1.077E+03	5.425E+01	8.748E-01	1.097E+00	2.242E-02
1.000E+00	0.	0.	0.	0.	0.	0.	6.000E+01	1.111E+00	1.111E+00	0.

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ETAD=8.4198E-01   PS(KW)=1.9176E+01   1-THD=7.6400E-01   1-WTT=7.0500E-01   V(KNOTS)=2.4204E+01       DESIGN TH(N)=1.2658E+03
                                                                             V(M/SEC)=1.2451E+01   CALCULATED TH(N)=1.2658E+03
```

TABLE 1 CONTINUED

X	AREA(M2)	XBAR(M)	YBAR(M)	IXO(M4)	IYO(M4)	MXO(N-M)	MYO(N-M)	MTB(N-M)	MQB(N-M)	MAXSTRESS(PA)
4.470E-01	4.550E-04	3.202E-02	0.	2.731E-09	7.821E-08	1.100E+01	3.540E+01	1.082E+01	7.238E+00	3.739E+07
5.600E-01	3.929E-04	3.202E-02	0.	1.758E-09	6.752E-08	7.037E+00	7.563E+01	6.498E+00	4.136E+00	3.134E+07
6.060E-01	3.792E-04	3.202E-02	0.	1.471E-09	6.364E-08	5.609E+00	4.749E+01	4.911E+00	3.124E+00	2.697E+07
6.530E-01	3.448E-04	3.202E-02	0.	1.108E-09	5.927E-08	4.146E+00	2.921E+01	3.576E+00	2.239E+00	2.239E+07
7.000E-01	3.250E-04	3.202E-02	0.	9.954E-10	5.587E-08	2.901E+00	2.083E+01	2.486E+00	1.531E+00	1.744E+07
7.970E-01	2.644E-04	3.128E-02	0.	5.613E-10	4.338E-08	9.885E-01	7.340E+00	8.502E-01	5.078E-01	1.026E+07
8.470E-01	2.276E-04	2.963E-02	0.	3.990E-10	3.352E-08	4.416E-01	3.416E+00	3.805E-01	2.241E-01	5.098E+06

X	RAKE	PI XTANBI	PI XTANB
4.470E-01	0.	3.631E-02	5.976E-01
5.170E-01	0.	1.295E+00	8.556E-01
5.680E-01	0.	1.372E+00	9.639E-01
6.060E-01	0.	1.395E+00	1.107E+00
6.530E-01	0.	1.450E+00	1.174E+00
7.000E-01	0.	1.479E+00	1.225E+00
7.970E-01	0.	1.588E+00	1.292E+00
8.470E-01	0.	1.479E+00	1.312E+00
8.960E-01	0.	1.443E+00	1.323E+00
9.470E-01	0.	1.359E+00	1.321E+00
1.000E+00	0.	1.110E+00	1.312E+00

WEIGHT OF BLADES(N)= 14.6900

WEIGHT OF PROP(BLADES+CYLINDRICAL HUB)(N)= 326.4865

CENTER OF GRAVITY OF PROP REFERENCED FROM MIDCHORD OF ROOT SECTION (- FWD, + AFT)/D= .004111

CENTER OF GRAVITY OF BLADES REFERENCED FROM MIDCHORD OF ROOT SECTION (- FWD, + AFT)/D= .098107

HUB DIMENSIONS/D
HUB DIAM = .447000
HUB LENGTH = .4470
MIDCHORD OF ROOT SECTION TO AFT END OF HUB = .2235

KELLERS MINIMUM EAR= .2946E+00

SPEED COEFF V/(ND) JS= .1807E+01

ADVANCE COEFF V(1-WTT)/(ND) JA= .1274E+01

DESIGN THRUST COEFF KT= .1800E+00

TORQUE COEFF KQ= .4719E-01

PROPULSIVE EFFICIENCY ETAD= .0420E+00

BURRILL THRUST COEFF TC= .2464E+00

BURRILL CAVITATION COEFF SIGMA(0.7)= .1200E+01

CLEARANCE AT HUB BETWEEN BLADES/D= -.02056395

CLEARANCE AT HUB BETWEEN FILLETS/D= -.04451592

TABLE 1 CONTINUED

PERFORMANCE OF SET OF CONTRAROTATING PROPELLERS

CTS= .26492

CPS= .22847

ETAD= .88591

TABLE 2

THRUST AND POWER LOADING COEFFICIENTS AND PROPULSIVE EFFICIENCY CALCULATED USING THE OLD AND NEW DESIGN METHODS

Performance Predictions	Old Method[1,2,3]	New Method
Thrust Loading Coefficient $(C_{TS})_{fwd}$	0.137	0.133
Thrust Loading Coefficient $(C_{Ts})_{aft}$	0.137	0.141
Thrust Loading Coefficient $(C_{Ts})_{CR}$	0.265	0.265
Power Loading Coefficient $(C_{Ps})_{fwd}$	0.113	0.108
Power Loading Coefficient $(C_{Ps})_{aft}$	0.116	0.128
Power Loading Coefficient $(C_{Ps})_{CR}$	0.222	0.229
Propulsive Efficiency $(\eta_D)_{CR}$	0.912	0.886

APPENDIX A

INPUT AND OUTPUT FORMATS FOR THE COMPUTER PROGRAM DEVELOPED

TABLE 1

List of dimensioned i¬put and output parameters used by computer program based on English and SI units

Parameter	English Units	SI Units	KSI(1)
Shaft power (P_S)	hp	KW	0.7457
Effective power (P_E)	hp	KW	0.7457
ρ_p	lbm/ft^3	kg/m^3	16.01846
V	knots(2)	m/s	0.514444
V	ft/sec	knots(2)	0.5924
D	ft	m	0.3048
H	ft	m	0.3048
ρ	$lbf\ sec^2/ft^4$	kg/m^3	515.3788
n	rev/min	rev/min(3)	1.0
T, weight	lbf	N	4.44822
V_r	ft/sec	m/s	0.3048
LI	lbf/ft	N/m	14.5939
M_{Tb}	in lbf	Nn	0.112985
M_{Qb}	in lbf	Nn	0.112985
M_{xo}	in lbf	Nn	0.112985
M_{yo}	in lbf	Nn	0.112985
Max Stress	lbf/in^2	Pa	6894.757
SKEW	deg	deg(3)	1.0
RAKE	deg	deg(3)	1.0
Mass polar moment of INERTIA	$lbm\ in^2$	kgm^2	0.00029264

(1) Multiply English Units by KSI to get SI Units.
(2) Computer program uses knots in both English Units option and SI Units option.
(3) These are not SI Units but are permitted to be used in the SI system according to International Standards Organization (150) Standard No. 1000.

APPENDIX A

INPUT FORMAT (FORWARD PROPELLER)

Card No.	Format	Parameter	Description of Input
1	F8.6	d/R	Axial distance between the forward and aft propeller planes nondimensionalized on forward propeller radius.
2	12A6	----	Identification of design input data.
3	F8.4	P_S or 0.0	Input the design shaft power if the power option is used. Input 0.0 if the design thrust option is used (see the section on the propeller design thrust and power options).
4	F8.4	1.0 or 5.0	Number of different speeds (V) and effective power values to be punched on Cards 5 and 6, respectively. Input 1.0 for the thrust option and 5.0 for the power option.
		ρ_P	Specific weight of propeller material (ρ_P) for weight calculations.
5	F8.4	V	Design speed (V). For the power option, input five different speeds in increasing order with the third speed being the best estimate of final speed. Input one speed for the thrust option.
6	F8.4	P_E	Design effective power values corresponding to input speeds on Card 5. (See Equation (1)).

Card No.	Format	Parameter	Description of Input
7	F8.6	D	Propeller diameter (D)
		$(1-w_T)$	Effective wake $(1-w_T)$
		(1-t)	Thrust deduction (1-t)
		H	Static head (H) at shaft centerline. (See section on Static Head).
		ρ	Density of water (ρ)
		Skew Angle (θ_s) Option	For a linear skew angle distribution input percent of skew in decimal form. For nonlinear skew input -1.0 and the skew angles in degrees (θ_s) must be punched on Cards 22 and 23.
		θ_R	Rake angle at blade tip in degrees. Use $+\theta_R$ value for blades raked aft and $-\theta_R$ for forward rake.
8	F8.6	1.0	Input 1.0
		C_D	Use CD$\geq$10 to input the radial distribution of drag coefficients (CD); 0<CD<10 to input a constant drag C_D=CD at all radial stations; CD=0 causes the computer program to calculate the radial distribution of drag coefficients using the equation $C_D=0.008\left(1+1.25(t/c)+125(t/c)^4\right)$; -10<CD<0 causes the computer program to use a constant frictional resistance $C_{FO}=ABS(C_{FO})$ in Equation 8, $C_D=C_{FO}\left(1+1.25(t/c)+125(t/c)^4\right)$; CD$\leq$-10 to input the radial distribution of frictional resistance (CFO) values to be used in Equation 8.
		tanβ Option 0.0 or 1.0	Input 0.0 if tanβ is calculated on the computer in the normal manner. Input 1.0 if tanβ distribution is arbitrary and punched on Cards 26 and 27.

Card No.	Format	Parameter	Description of Input
9	F8.6	Z	Number of blades
10	F8.6	A_E/A_O	Expanded area ratio
11	F8.6	n	Revolutions per unit time
12-13	F8.6	x	Nondimensional radial station (eleven values arbitrary spaced from propeller hub to tip)
14-15	F8.6	$(1-w_x)$	Propeller wake $(1-w_x)$ corresponding to input x values
16-17	F8.6	$\tan\beta_I$	Tangent of hydrodynamic flow angle $(\tan\beta_I)$ corresponding to input x values. If Lerbs optimum $\tan\beta_I$ distribution is desired, 0.0 values must be punched in these cards
18-19	F8.6	c/D	Section chord lengths corresponding to input x values
20-21	F8.6	t/c	Thickness-chord ratios corresponding to input x values
22-23	F8.6	θ_s Optional	Blade skew angles corresponding to input x values to be input only if -1.0 for skew option is punched in Card 7. Otherwise Cards 22 and 23 must not be used as input cards.
24-25	F8.6	C_D Optional	Section drag coefficient corresponding to input values if CD>10 on Card 8; frictional resistance of section if CD$\leq$10.

Card No.	Format	Parameter	Description of Input
26-27	F8.6	tanβ Optional	Tangent of advance angle corresponding to input x values to be input only if 1.0 for tanβ option is punched on Card 8. Otherwise Cards 26 and 27 must not be used as input.
28-29	F8.6	g_a	Distance factors (g_a) corresponding to input x values from Reference 1 and Figure 1.

INPUT FORMAT (AFT PROPELLER)

Card No.	Format	Parameter	Description of Input
30	12A6		Identification of design input data.
31	F8.4	P_S or 0.0	Input the design shaft power delivered at the propeller if the power option is used. Input 0.0if the design thrust option is used (see the section on the propeller design thrust and power options).
32	F8.4	1.0 or 5.0	Number of different speeds (V) and effective power values to be punched on Cards 33 and 34, respectively. Input 1.0 for the thrust option and 5.0 for the power option.
		ρ_P	Specific weight of propeller material (ρ_M) for weight calculations.
33	F8.4	V	Design speed (V). For the power option. Input five different speeds in increasing order with the third speed being the best estimate of final speed. Input one speed for the thrust option.
34	F8.4	P_E	Design effective power values corresponding to input speeds on Card 33. (See Equation (1)).
35	F8.6	0.0	Input 0.0 for aft propeller diameter which is calculated on the computer.
		$(1-w_T)$	Effective wake $(1-w_T)$
		$(1-w_T)$	Thrust deduction (1-t)

Card No.	Format	Parameter	Description of Input
		H	Static Head (H) at shaft centerline. (See section on Static Head).
		ρ	Density of water (ρ).
		Skew Angle (θ_s) Option	For a linear skew angle distribution input percent of skew in decimal form. For nonlinear skew input -1.0 and the skew angles in degrees (θ_s) must be punched in Cards 50 and 51.
		θ_R	Rake angle at blade tip in degrees. Use $+\theta_R$ value for blades raked aft and $-\theta_R$ for forward rake.
36	F8.6	1.0	Input 1.0
		C_D	Use CD$\geq$10 to input the radial distribution of drag coefficients (CD); 0<CD<10 to input a constant drag C_D=CD at all radial stations; CD=0 causes the computer program to calculate the radial distribution of drag coefficients using the equation $C_D=0.008(1+1.25((t/c)+125(t/c)^4)$; -10<CD<0 causes the computer program to use a constant frictional resistance C_{FO}=ABS(C_{FO}) in Equation 8, $C_D=C_{FO}(1+1.25(t/c)+125(t/c)^4)$; CD$\leq$-10 to input the radial distribution of frictional resistance (CFO) values to be used in Equation 8.
		$\tan\beta$ Option 0.0 or 1.0	Input 0.0 if $\tan\beta$ is calculated on the computer in the normal manner. Input 1.0 if $\tan\beta$ distribution is arbitrary and punched on Cards 54 and 55.
37	F8.6	Z	Number of blades
38	F8.6	A_E/A_O	Expanded area ratio

Card No.	Format	Parameters	Description of Input
39	F8.6	n	Revolutions per unit time
40-41	F8.6	x	Nondimensional radial station (eleven values arbitrarily spaced from propeller hub to tip).
42-43	F8.6	$(1-w_x)$	Propeller wake $(1-w_x)$ corresponding to input x values.
44-45	F8.6	$\tan\beta_I$	Tangent of hydrodynamic flow angle ($\tan\beta_I$) corresponding to input x values. If Lerbs optimum $\tan\beta_I$ distribution is desired, 0.0 values must be punched in these cards.
46-47	F8.6	c/D	Section chord lengths corresponding to input x values.
48-49	F8.6	t/c	Thickness-chord ratios corresponding to input x values.
50-51	F8.6	θ_s Optional	Blade skew angles corresponding to input x values to be input only if -1.0 for skew option is punched in Card 35. Otherwise Cards 50 and 51 must not be used as input cards.
52-53	F8.6	C_D Optional	Section drag coefficient corresponding to input values if CD>10 on Card 8; frictional resistance of section if CD≤10.
54-55	F8.6	$\tan\beta$ Optional	Tangent of advance angle corresponding to input x values to be input only if 1.0 for $\tan\beta$ option is punched on Card 8. Otherwise Cards 54 and 55 must not be used as input.

TABLE 1

A DESCRIPTION OF THE OUTPUT PARAMETERS

Computer Parameter	Parameter	Description of Output
V	V	Speed (input)
PE	P_E	Effective power (input)
D	D	Diameter (input)
Z	Z	Number of blades (input)
H	H	Static head (input)
RHO	ρ	Density of fluid (input)
AE/AO	A_E/A_O	Expanded area ratio (input or Equation (6))
CPSI	-----	Nonviscous power coefficient (Equation (11) when $\epsilon=0$)
CTSI	-----	Nonviscous thrust coefficient (Equation (9) when $\epsilon=0$)
XI	x	Nondimensional radii (x)
DCTSI	dC_{Tsi}	Local nonviscous thrust coefficient (Defined in Equation (9))
DCPSI	dC_{Psi}	Local nonviscous power coefficient (Defined in Equation (11))
CPS	C_{PS}	Power loading coefficient (Equation (11))
CTS	C_{TS}	Thrust loading coefficient (Equation (9))
TANBI	$\tan\beta_I$	Tangent of hydrodynamic flow angle
TANB	$\tan\beta$	Tangent of advance angle
G	G	Nondimensional circulation
UT/2V	$U_T/2V$	Tangential velocity induced at lifting line
UA/2V	$U_A/2V$	Axial velocity induced at lifting line

Computer Parameter	Parameter	Description of Output
VR	V_r	Section inflow velocity, Equation (22)
SIGMAX	σ	Section cavitation number, Equation (25)
CL	C_L	Section lift coefficient
ALI	α_i	Section two-dimensional ideal angle of attack in degrees for NACA a=0.8 meanline, Equation (24)
FM/C	f_M/c	Section two-dimensional maximum camber ratio for NACA a=0.8 meanline, Equation (23)
CD/CL	ϵ	Section drag-lift ratio ($=C_D/C_L$)
F(X)	F(x)	Parameter for calculations section fluctuating angles of attack, Equation (28)
LI	L I	Propeller load distribution for finite element stress calculations, Equation (22)
SKEW ANGLE	θ_s	Propeller skew angle in degrees
(C/R) LE	$(c/R)_{LE}$	Chord lengths for lifting surface pitch and camber calculations, Equation (32)
(C/R) TE	$(c/R)_{TE}$	Chord lengths for lifting surface pitch and camber calculations, Equation (33)
T/R	t/R	Ratio of section thickness to radius
PC	η_D	Estimated propulsive efficiency, Equation (13)
PS	-----	calculated shaft power delivered at the propeller, Equation (13)
1-T	(1-t)	Propeller thrust deduction
1-WT	$(1-w_T)$	Propeller effective wake.

Computer Parameter	Parameter	Description of Output
TH(N)	T	Design thrust, Equation (9)
TH(N)	T	Calculated thrust, Equation (9)
A	-----	Area of section
XBAR	-----	Longitudinal position about x axis parallel to nose-tail line from centroid
YBAR	-----	Vertical distance about y axis perpendicular to nose-tail line from centroid
IXO	-----	Moment of inertia about x axis parrallel to nose-tail line
IYO	-----	Moment of inertia about y axis perpendicular to nose-tail line
MTB	M_{Tb}	Bending moment due to thrust, Equation (18)
MQB	M_{Qb}	Bending moment due to torque, Equation (19)
MXO	M_{xo}	Bending moment about the x axis, Equation (20)
MYO	M_{yo}	Bending moment about the y axis, Equation (21)
MAX STRESS	------	Maximum stress, Reference 10
RAKE ANGLE	θ_R	Rake angle in degrees
PIXTANBI	$\pi x \tan\beta_I$	Hydrodynamic pitch angle
PIXTANB	$\pi x \tan\beta$	Advance angle
WEIGHT OF BLADES	(W_B)	Equation (36), W_H=0

Computer Parameter	Parameter	Description of Output
WEIGHT OF PROP (BLADES + CYLINDRICAL HUB)	(W_P)	Equation (36)
CENTER OF GRAVITY OF PROP	CG	Equation (37)
CENTER OF GRAVITY OF BLADES	----o-	Equation (37), $M_H=0$
KELLERS MINIMUM EAR	$(A_E/A_O)_K$	Equation (31)
SPEED COEFF(JV)	J_V	Equation (15)
ADVANCE COEFF (JA)	J	Equation (14)
THRUST COEFF (KT)	K_T	Equation (16)
TORQUE COEFF (KQ)	K_Q	Equation (17)
PROPULSIVE EFFICIENCY ETAD	η_D	Equation (13)
BURRILL THRUST COEFF (TC)	τ_C	Equation (29)
BURRILL CAVITATION COEFF	$\sigma_{0.7}$	Equation (30)
CLEARANCE AT HUB BETWEEN BLADES	G_Z	Equation (34)

Computer Parameter	Parameter	Description of Output
CLEARANCE AT HUB BETWEEN FILLETS	G_F	Equation (35)
CTS	$(C_{TS})_{CR}$	Thrust loading coefficient for set of contra-rotating propellers (Equation 10)
CPS	$(C_{PS})_{CR}$	Power loading coefficient for set of contra-rotating propellers (Equation 12)
ETAD	$(\eta_D)_{CR}$	Propulsive efficiency for set of contra-rotating propellers (Equation 13)

APPENDIX B

FORTRAN LISTING OF COMPUTER PROGRAM

```
      PROGRAM GMAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      COMMON/GWEIGHT/X,CHORD,THICKNS,CAMBER,PITCH,SKEWR,DIAM,ZZ,DEN,RAKE
     1,ST
     1,PI,PP7,PP8,PP9,PP11,EWAKE,VS,FPS,SIGMA,EAR,BT
      DIMENSION B(38,38),B1(181),B2(181),B3(181),B4(362),B5(362),B6(362)
     1,B7(181),B8(181),B9(181),B10(181),B11(181),B12(181), B13(181),B14(
     2181),B15(181),AZ(38,38),BH(38,38),C(38,38),CC(38,38),INDEX(38,3)
     3,A(38,72),BB(38,72)
      COMMON B,B1,B2,B3,B4,B5,B6,B7,B8,B9,B10,B11,B12,B13,B14,B15,AZ,BH,
     1C,CC,INDEX,A,BB
      COMMON ID,JB,JC,JD,JDD,JFF
      COMMON CL1(11)
      DIMENSION CHORD(38),THICKNS(38),CAMBER(38),PITCH(38),SKEWR(38)
     1,X(38),BETAI(38),BT(11)
       DIMENSION X3(38),X4(38),X5(38),X6(38),VEL(9),EHP(9),BLA(9),EXX(9)
      DIMENSION AZZ(38,38)
      DIMENSION ASHP(9)
      DIMENSION XMM(9)
      DIMENSION CAV(9),CAF(9)
      DIMENSION FX(11),BPJ(11)
      DIMENSION VEL1(9),EHP1(9)
      DIMENSION E(11,14,2)
      DIMENSION CONST(11),G(11),H(11)
       DIMENSION SVL(9),SPE(9)
      DIMENSION UA(11),UT(11),KV(11),UR(11),UA1(11,2),UT1(11,2),UR1(11,2
     1)
      DIMENSION ABC(11,9)
      DIMENSION DEX(11,3,2),COM(12,2)
      DIMENSION FWDSHP(3),AFTSHP(3)
      DIMENSION BZ(111)
      DIMENSION AX(11),RAK(11)
      DIMENSION VSUBASO(11),VSUBF(11),PLFT(11),AV(11),BV(11)
      COMMON CCONE(11),CCTWO(11),CCTHR(11),CCFOR(11)
      DIMENSION AREA(7),YBAR(7),YBAR(7),AYEXO(7),AYEYO(7),EMXO(7),EMYO(7
     1),EMTB(7),EMOB(7),STRMAX(7)
      DIMENSION PXTBI(11),PXTB(11)
      DIMENSION SX(7)
      COMMON PP1,PP2,PP3,PP4,PP5,PP6,PP10
      DIMENSION GA11(11)
      DIMENSION HUBDIM(6,2)
      DIMENSION CPT(2),CPS(2),CTS(2)
       COMMON /WRT/ JPR
       READ(5,406) DEX(1,2,1)
 406   FORMAT(F8.4)
       JPR=0
       IPO=1
       IOCR=0
      XDD=4.0
      IDC=XDD
      PI=3.14159265358979
       DSI=16.01846
       PWR=.7456999
       VSI=.5144444
       ELF=.3048
       ELI=.0254
       EL2=ELI*ELI
       EL4=EL2*EL2
```

```
      SIM=.1129848
      SMX=6894.757
      SWT=4.44822
      RHOSI=515.3788
      IPR=C
      JG=0
      DO 813 K=1,2
      XRPM=1.0
      XZZ=1.C
      XEA=1.C
      JG=JG+1
      READ(5,830) (COM(I,K),I=1,12)
  830 FORMAT(12A6)
      READ(5,1000C) SPWR
      SHP=SPWR/PWR
      READ(5,10009) XVV,DSN
      HUB=0.
      DEN=DSN/DSI
      IRPM=XRPM
      IVV=XVV
      READ(5,10009) (SVL(I),I=1,IVV)
      READ(5,10009) (SPE(I),I=1,IVV)
      READ(5,10009) SDM,EWAKE,ETHRUS,SHD,SRO,XPS,RAKE
      DO 409 I=1,IVV
      VEL(I)=SVL(I)/VSI
  409 EHP(I)=SPE(I)/PWR
      DIA=SDM/ELF
      HEAD=SHD/ELF
      RHO=SRO/RHOSI
      IF(SHP) 103,102,103
  103 SHP=SHP/2.0
      NXVV=XVV
  102 CONTINUE
      READ(5,10009) TANBI,CD,TANB
      B(2,1)=CD
      JC=11
      IZZ=XZZ
      IEA=XEA
      READ(5,10009)(BLA(I),I=1,IZZ)
      BLAS=BLA(1)
      READ(5,10009)(EXX(I),I=1,IEA)
      EXXS=EXX(1)
      READ(5,10009) (XMM(I),I=1,IRPM)
      READ(5,10009) (X3(I),I=1,JC)
      READ(5,10009) (X4(I),I=1,JC)
      READ(5,10009) (X5(I),I=1,JC)
      READ(5,10009) (X6(I),I=1,JC)
      READ(5,10009) (AZZ(I,25),I=1,JC)
      IF(XPS) 6,7,7
    6 READ(5,10009) (AZZ(I,24),I=1,JC)
      DO 26 I=1,JC
      AZZ(I,38)=AZZ(I,24)
   26 CONTINUE
7     CONTINUE
      IF(ABS(CD).GE.10.) READ(5,10009) (B(I,7),I=1,JC)
      IF(CD.GE.10.) GO TO 10010
      TM=P(2,1)
```

```
      CFO=.008
      IF(CO.GT.0.) CFO=1.
      IF(CO.GT.-10. .AND.CO.LT.0.) CFO=-CO
      DO 10007 I=1,JC
      IF(CO.LE.0.) TM=1.+1.25*AZZ(I,25)+125.*AZZ(I,25)**4
      IF(CO.LE.-10.) CFP=B(I,7)
10007 B(I,7)=CFO*TM
10008 FORMAT(72H
     1                )
10000 FORMAT(F8.4)
10009 FORMAT(9F8.4)
10010 IF(TANB.LE.0.) READ(5,10009) (B(I,8),I=1,JC)
      IF(IOCP.NE.0) GO TO 57
      IF(K.NE.1) GO TO 57
      READ(5,10009) (GA11(I),I=1,11)
   57 CONTINUE
      IF(HUB.NE.0.) READ(5,10009) (HUBDIM(I,K),I=1,6)
      D(10,1,K)=XVV
      D(11,1,K)=XRPM
      DO 802 I=1,IVV
      D(I,1,K)=VEL(I)
  802 D(I,2,K)=EHP(I)
      D(11,2,K)=EWAKE
      D(1,3,K)=ETHRUS
      D(6,3,K)=XPS
      D(7,3,K)=SHP
      D(9,3,K)=CD
      D(10,3,K)=TANB
      D(10,2,K)=DIA
      D(2,3,K)=HEAD
      D(3,3,K)=RHO
      D(4,3,K)=XZZ
      D(5,3,K)=XEA
      D(8,3,K)=TANBI
      D(11,3,K)=DEN
      D(11,4,K)=HUB
      DO 803 I=1,IZZ
  803 D(I,4,K)=BLA(I)
      DO 804 I=1,IEA
  804 D(I,5,K)=EXX(I)
      DO 805 I=1,IRPM
  805 D(I,6,K)=XMM(I)
      DO 808 I=1,JC
      D(I,7,K)=X3(I)
      D(I,8,K)=X4(I)
      D(I,9,K)=X5(I)
      D(I,10,K)=X6(I)
  808 D(I,11,K)=AZZ(I,25)
      IF(XPS) 806,807,807
  806 DO 125 I=1,JC
  125 D(I,12,K)=AZZ(I,24)
  807 CONTINUE
      DO 809 I=1,JC
  809 D(I,13,K)=B(I,7)
  810 IF(TANB) 812,812,811
  811 DO 126 I=1,JC
  126 D(I,14,K)=B(I,8)
```

```
  812 CONTINUE
      DEX(1,1,K)=4.0
      DEX(2,1,K)=11.0
      DEX(3,1,K)=1.0
      DEX(1,2,2)=-DEX(1,2,1)
      JT=11
  813 CONTINUE
      IC=-2
      JN=0
      JQ=0
      IK=1
      NF=0
      NTT=0
      IF(SHP) 90,91,90
   91 NXVV=1
   90 DO 10073 NK=1,NXVV
  105 CONTINUE
      NT=0
      NTT=NTT+1
      IF(NK.GT.1) IDD=2
      DO 10072 NIT=1,IDD
      NT=NT+1
      XVV=D(10,1,IK)
      IVV=XVV
      XRPM=D(11,1,IK)
      IF(SHP) 152,152,153
  153 IF(NTT.EQ.NXVV+1) GO TO 151
  152 CONTINUE
      DO 820 I=1,IVV
      VEL(I)=D(I,1,IK)
  820 EHP(I)=D(I,2,IK)
  151 CONTINUE
      DO 1 I=1,IVV
      CAV(I)=VEL(I)
    1 CAE(I)=EHP(I)
      DIA=D(10,2,IK)
      EWAKE=D(11,2,IK)
      ETHRUS=D(1,3,IK)
      HEAD=D(2,3,IK)
      RHO=D(3,3,IK)
      XZZ=D(4,3,IK)
      XEA=D(5,3,IK)
      XPS=D(6,3,IK)
      SHP=D(7,3,IK)
      TANBI=D(8,3,IK)
      CD=D(9,3,IK)
      TANB=D(10,3,IK)
      DEN=D(11,3,IK)
      HUB=D(11,4,IK)
      DO 821 I=1,IZZ
      BLA(I)=D(I,4,IK)
  821 BLAS=BLA(1)
      DO 822 I=1,IEA
      EXX(I)=D(I,5,IK)
  822 EXXS=EXX(1)
      DO 823 I=1,IRPM
  823 XMM(I)=D(I,6,IK)
```

```
      DO 824 I=1,JC
      X3(I)=D(I,7,IK)
      X4(I)=D(I,8,IK)
      X5(I)=D(I,9,IK)
      X6(I)=D(I,10,IK)
  824 AZZ(I,25)=D(I,11,IK)
      IF(XPS) 825,826,826
  825 DO 127 I=1,JC
  127 AZZ(I,24)=D(I,12,IK)
  826 CONTINUE
  827 DO 128 I=1,JC
  128 B(I,7)=D(I,13,IK)
  828 IF(TANB) 831,831,829
  829 DO 129 I=1,JC
  129 B(I,8)=D(I,14,IK)
  831 CONTINUE
      DO 15 I=1,JC
   15 AZZ(I,23)=X3(I)
      JC1=JC-1
      DO 16 I=2,JC1
   16 AZZ(I,19)=X3(I+1)
      AZZ(1,19)=X3(1)
      DO 4 I=1,11
      AZZ(I,36)=AZZ(I,25)
4     AZZ(I,37)=AZZ(I,23)
      DO 10072 IE=1,IZZ
      B(9,2)=BLA(IE)
      XSX=XPS*(360.0/B(9,2))
      AS1=XSX/(1.0-X3(1))
      AS2=XSX-AS1
      DO 10072 KE=1,IEA
      DO 10072 IRP=1,IRPM
      RPM=XMM(IRP)
      EAR=EXX(KE)
      DO 100 I=1,JC
      B(I,3)=X3(I)
      B(I,4)=X4(I)
      B(I,5)=X5(I)
      IF(XPS) 14,13,13
13    CONTINUE
      AZZ(I,24)=AS1*X3(I)+AS2
      AZZ(1,24)=0.0
      GO TO 166
   14 AZZ(I,24)=AZZ(I,38)
  166 CONTINUE
      AZZ(I,38)=AZZ(I,24)
  100 CONTINUE
      DO 10051 LE=1,JC
10051 B(LE,6)=(BLAS*EAR*X6(LE))/(B(9,2)*EXXS)
      DO 10052 LE=1,JC
10052 AZZ(LE,25)=AZZ(LE,36)*B(LE,6)
      DO 30 I=1,9
      VEL(I)=CAV(I)
30    FHP(I)=CAE(I)
      B(5,2)=XMM(IRP)/60.0
      IVV=XVV
      IVA=1
```

```
10046 IF(SHP) 51,52,51
   52 DO 53 IG=1,IVV
      VEL1(IG)=VEL(IG)
   53 EHP1(IG)=EHP(IG)
      IV=1
      GO TO 54
   51 CONTINUE
      IV=1
      IF(NTT.EQ.NXVV+1) GO TO 155
      VEL1(1)=VEL(NK)
      EHP1(1)=EHP(NK)
      GO TO 54
  155 VEL1(1)=VEL(1)
      EHP1(1)=EHP(1)
   54 CONTINUE
   21 DO 5 I=1,11
      AZZ(I,25)=AZZ(I,36)
5     AZZ(I,23)=AZZ(I,37)
      B(6,2)=(325.86*EHP1(IV))/(VEL1(IV)*ETHRUS)
      B(7,2)=1.688*VEL1(IV)
      AJJ=1.0
      NN=0
10001 BJ=1.0
      JB=BJ
10002 FORMAT( 3I3)
10003 CONTINUE
      DDJ=1.0
      JEE=TANBI
      JDD=DDJ
      B6(361)=1.0
      JD=.666667*FLOAT(JC)
      B(1,1)=0.0
      B(2,1)=CD
      B(3,1)=TANB
      B(4,1)=0.6
      B(6,1)=0.0
      B(7,1)=0.0
      B(8,1)=0.0
      B(9,1)=0.0
      B(1,2)=1.0
      B(2,2)=1.0
      B(3,2)=RHO
      B(5,1)=EWAKE
      B(3,2)=DIA
      B(4,2)=HEAD
      RSL=B(7,2)/(3.14159265*B(5,2)*B(3,2))
10012 IF(B(1,5)) 10017,10017,10019
10017 CONTINUE
      IF(B(5,1)) 800,800,801
800   B(5,1)=B(JD,4)
801   CONTINUE
      DO 10018I=1,JC
10018 B(I,5)=(RSL*SQRT(B(5 ,1))*SQRT(B(I,4)))/(B(I,3)*B(4,1))
10019 NN=NN+1
      HUBL=X3(1)*DIA/2.0
      ADJS=(X3(11)*DIA/2.0)-HUBL
      DO 35 I=1,11
```

```
   35 RAK(I)=((X3(I)*DIA/2.0)-HUBL)*RAKE/ADJS
      IPR=IPR+1
       IF(JPP.NE.2) GO TO     10087
       SDM=DIA*ELF
      WRITE(6,130)
  130 FORMAT(1H1)
      IF(IK-1) 115,115,116
  115 WRITE(6,117)
  117 FORMAT(43X,*FORWARD PROP OF CONTRAROTATING SET*)
      GO TO 118
  116 WRITE(6,119)
  119 FORMAT(45X,*AFT PROP OF CONTRAROTATING SET*)
  118 CONTINUE
      WRITE(6,830) (COM(I,IK),I=1,12)
       TSHP=2.*SFWR
       IF(SHF.EQ.0.) WRITE(6,410)
       IF(SHF.NE.0.) WRITE(6,10020) TSHP
  410  FORMAT(2X,*THRUST OPTION*)
10020  FORMAT(2X,*PS(KW)=*,1X,1PE12.4)
       WRITE(6,10026) XVV,DSN
10026 FORMAT(2X,*NO OF V=*,F5.1,4X,                         *DENSITY OF PROP
     1(KG/M3)=*,F10.2,4X)
       WRITE(6,10027) (SVL(I),I=1,IV9)
10027  FORMAT(2X,*V(M/SEC)=*,1P9E12.4)
       WRITE(6,10045) (SPE(I),I=1,IV9)
10045  FORMAT(2X,*PE(KW)=*,2X,1P9F12.4)
       WRITE(6,10028)SDM,EWAKE,ETHRUS,SHD,SRO,XPS,RAKE
10028  FORMAT(2X,*D(M)=*F8.4,4X,*1-WTT=*,F8.4,4X,*1-THD=*F8.4,4X,*H(M)=*
     2 ,F9.4,4X,*RHO(KG/M3)=*F10.4/2X,*TETS OPT= *,F6.3,3X,*RAKE OPT= *,
     3 F6.3)
      WRITE(6,10029) TANBI,CD,TANB
10029 FORMAT(2X,*TANBI OPT= *,F4.2,4X,*DRAG OPT= *,F7.4,4X,*TANB OPT= *,
     1F4.2)
      WRITE(6,10030)(BLA(I),I=1,IZZ)
10030  FORMAT(2X,*Z=*,10X,1P9E12.4)
      WRITE(6,10031)(EXX(I),I=1,IEA)
10031  FORMAT(2X,*AE/A0=*6X,1P9E12.4)
      WRITE(6,10032)(XMM(I),I=1,IRPM)
10032  FORMAT(2X,*N(REV/MIN)= *,1P9E12.4)
       WRITE(6,10042)
      WRITE(6,10033)(X3(I),I=1,JC),(X4(I),I=1,JC),(X5(I),I=1,JC),(X6(I),
     1I=1,JC),(AZZ(I,25),I=1,JC)
10033 FORMAT(2X,*X=          *,1P9E12.4/10X,1P2E12.4/2X,*1-WX=    *,1P9E12.4/
     110X,1P2E12.4/2X,*TANBI=  *,1P9F12.4/10X,1P2E12.4/2X,*C/D=     *,1P9
     2E12.4/10X,1P2E12.4/2X,*T/C=     *,1P9E12.4/10X,1P2E12.4)
      IF(XPS) 22,23,23
   22 WRITE(6,10036) (AZZ(I,24),I=1,JC)
10036  FORMAT(2X,*TETS=    *,1P9E12.4/10X,1P2F12.4)
   23 CONTINUE
      IF(CD) 24,24,25
   24 WRITE(6,10037)(B(I,7),I=1,JC)
10037 FORMAT(2X,*CD=       *,1P9E12.4/10X,1P2E12.4)
   25 CONTINUE
10043  FORMAT(4X,*D(M)=*1PE10.4,*    N(REV/MIN)=*1PE10.4,*    Z=*,1PE10.4,
     2  *    AE/A0=*1PE10.4     )
10044  FORMAT(3X,*ETAD=*,
     2                   1PE10.4,2X,*PS(KW)=*,1PE10.4,3X,*1-THD=*,1PE10.4,
```

```
      2  3X,*1-WTT=*,1PE10.4,3X,
      2 *V(KNOTS)=*1PE10.4,3X,*     DESIGN TH(N)=*,1PE10.4,
      3 /,78X,*V(M/SEC)=*,1PE10.4,3X,*CALCULATED TH(N)=*,1PE10.4)
        WRITE(6,10042)
        WRITE(6,10043) SDM,RPM,B(9,2),EAR
10087  VK=B(7,2)/1.6878
        VMS=B(7,2)*ELF
       DO 10090 I=1,JC
       AZZ(I,25)=AZZ(I,25)*B(I,6)
10090 B(I,30)=B(I,5)
10024 FORMAT(1P9E12.4)
       IF(JN) 65,65,66
   65 CONTINUE
       XMM1=RPM/60.0
       IF(TANR) 10034,10034,101
10034 DO 10035 I=1,JC
10035 B(I,8)=RSL/B(I,3)*B(I,4)
       CW1=B(7,8)
  101 CONTINUE
       GO TO 67
66     CONTINUE
       DO 68 I=1,JC
       CONST(I)=PI*XMM1*DIA*X3(I)/B(7,2)
       G(I)=UA(I)+X4(I)
       H(I)=CONST(I)-UT(I)
   68 B(I,8)=G(I)/H(I)
       CW2=B(7,8)
       DO 31 I=1,11
31     B(I,8)=CW1/CW2*B(I,8)
       IF(IK-2) 33,32,33
32     DO 34 I=1,11
34     B(I,8)=D(10,2,1)*B(I,8)/D(10,2,2)
33     CONTINUE
   67 CONTINUE
       IF(SHP) 85,85,86
   85 JN=JN+1
   86 CONTINUE
       ALPHA=6.2831853/72.
       DO 12 I=1,36
       DO 12 J=1,72
       AC=ALPHA*FLOAT((J-1)*I)
       A(I,J)=SIN(AC)
   12 BB(I,J)=COS(AC)
       AJJ=1.0
20003 IF(JEE)2,2,3
2      AJJ=1.
       GO TO 47
3      DO 209 IDC=1,2
       DO 201 I=1,JC
201    B(I,30)=B(1,30)*AJJ
       B14(41)=.975
       B14(42)=1.000
       B14(43)=1.025
       DO 215 IJ=41,43
       IJT=IJ+4
       IJP=IJ+8
       DO 216 I=1,JC
```

```
216     B(I,5)=B(I,30)*B14(IJ)
        CALL SUB
        B14(IJT)=B5(362)
        B14(IJP)=B6(362)
  215 CONTINUE
        B15(41)=1.0
        B15(44)=1.0
        B15(47)=1.0
        B15(42)=B14(41)
        B15(45)=B14(42)
        B15(48)=B14(43)
        B15(43)=B14(41)**2
        B15(46)=B14(42)**2
        B15(49)=B14(43)**2
        IF(B(1,2)) 8,8,9
9       CC(1,1)=B14(45)
        CC(2,1)=B14(46)
        CC(3,1)=B14(47)
        TTT=B(6,2)/((B(8,2)*B(3,2)**2*3.1415927*B(7,2)**2)/3.)
        GO TO 10
8       CC(1,1)=B14(49)
        CC(2,1)=B14(50)
        CC(3,1)=B14(51)
        TTT=550.*B(6,2)/((B(8,2)*B(3,2)**2*3.1415927*B(7,2)**3)/8.)
10      DO 11 I=1,3
        DO 11 J=1,3
        K=3*(J-1)+I
11      C(J,I)=B15(K+40)
        B10(181)=3
        CALL SIMEQ(3,C,CC)
10048 AJJ=(-CC(2,1)+SQRT(CC(2,1)**2-4.*CC(3,1)*(CC(1,1)-TTT)))/(2.*CC(3,
     11))
209     CONTINUE
50      B6(361)=-1.0
        JEE=0
48      DO 49 I=1,JC
49      B(I,5)=B(I,30)*AJJ
47      CONTINUE
        CALL SUB
        PP11=B15(161)*ETHRUS
        PP12=EHP1(IV)/PP11
        TH2=B(6,2)
        ATHR=B(8,2)/8.0*3.14159*(B(3,2)**2)*(B(7,2)**2)*PP7
        ASHP(IV)=PP12
        IF(SHP) 55,56,55
   55 IVV=1
   56 IV=IV+1
      IF(IVV-IV) 10050,21,21
10050 CONTINUE
      DO 10049 IX=1,IV
      EHP(IX)=EHP1(IX)
10049 VEL(IX)=VEL1(IX)
      DO 40050 I=1,JC
      AZZ(I,26)=B(I,14)
      AZZ(I,27)=B(I,5)
      BII=ATAN(AZZ(I,27))
      CII=(AZZ(I,24)*B(I,3))/(57.2958*COS(BII))
```

```
      AZZ(I,28)=CII-B(I,6)
      AZZ(I,29)=CII+B(I,6)
      AZZ(I,30)=B(I,6)
      AZZ(I,31)=B(I,4)
      AZZ(I,32)=B(I,12)
      AZZ(I,33)=B(I,13)
40050 AZZ(I,34)=AZZ(I,25)*2.0
      DO 36 I=1,JC
   36 AX(I)=AZZ(I,34)
      IF(AZZ(11,25).NE.0.) GO TO 5555
      SLP=(AZZ(9,34)-AZZ(6,34))/(AZZ(9,23)-AZZ(6,23))
      YINT=AZZ(9,34)-(AZZ(9,23)*SLP)
      AZZ(10,34)=(SLP*AZZ(10,23))+YINT
      AZZ(11,34)=(SLP*AZZ(11,23))+YINT
 5555 CONTINUE
      DO 40052 K=26,34
      DO 40051 J=1,11
      B11(J)=B(J,3)
40051 B3(J)=AZZ(J,K)
      DO 40052 I=1,11
      S1=AZZ(I,23)
      CALL DISCOT(S1,S1,B11,B3,B3,-120,JC,0,S2)
40052 AZZ(I,K)=S2
40056 FORMAT(1PE10.3,1P10E11.3)
      DO 5050 I=1,JC
      AZZ(I,2)=B(I,2)
      B(I,20)=B(I,15)
      B(I,21)=B(I,5)
      BII=ATAN(B(I,21) )
      B(I,22)=B(I,38)
      B(I,23)=B(I,6)
      B(I,24)=AZZ(I,24)
      B(I,25)=AZZ(I,25)
5050  B(I,24)=(B(I,24)*B(I,3))/(57.2958*COS(BII))
      BT(11)=B(11,5)
      DO 5001 I=1,10
5001  B1(I)=AZZ(I,19)
      DO 50030 K=20,24
      DO 50020 J=1,11
      B11(J)=B(J,3)
50020 B3(J)=B(J,K)
      DO 50030 I=1,10
      S1=B1(I)
      CALLDISCOT(S1,S1,B11,B3,B3,-120,JC,0,S2)
50030 B(I,K)=S2
      DO 50040 K=20,24
      DO 50040 I=1,10
50040 AZZ(I,K)=B(I,K)
      CALL STRESS(AZZ,AREA,XBAR,YBAR,AYEXO,AYEYO,EMXO,EMYO,EMTB,EMQB,STR
     1MAX)

C          THE FOLLOWING STATEMENTS HAVE BEEN ADDED IN ORDER TO SEND THE R
C          VALUES TO SUBROUTINE WEIGHT.  CHORD,THICKNESS, AND CAMBER ARE I
C          PITCH AND SKEWR ARE IN RADIANS.
      DO 999 I=1,JC
      VS=VK*1.6878
      X(I)=B(I,3)
```

```
      IF(X(I).NE.0.7) GO TO 6001
      SIGMA=B(I,19)
      GO TO 6000
 6001 IF(X(I).LE.0.65) GO TO 6000
      IF(X(I).GE.0.75) GO TO 6000
      SIGMA=B(I,19)
 6000 CONTINUE
      CHORD(I)=B(I,6)*DIAM
      THICKNS(I)=AZZ(I,34)*DIAM/2.
      PITCH(I)=ATAN(B(I,5))
      BBJ(I)=ATAN(B(I,8))
      IF(CL1(I)) 28,27,28
   27 FX(I)=0.0
      GO TO 29
   28 CONTINUE
      FX(I)=1.0/(1.0+(6.2832*TAN(PITCH(I)-BBJ(I))/CL1(I)))
   29 CONTINUE
      BETAI(I)=PITCH(I)*57.2958
      SKEWR(I)=AZZ(I,38)/57.2958
      AZZ(I,34)=AX(I)
      AV(I)=(B(I,4)+B(I,12))**2
      BV(I)=(B(I,4)/B(I,8)-B(I,13))**2
      VSUBRSQ(I)=VS**2*(AV(I)+BV(I))
      VSUBR(I)=SQRT(VSUBRSQ(I))
       PLFT(I)      =.5*RHO*VSUBRSQ(I)*CL1(I)* B(I,6)*DIA*14.5939
  999 CAMBER(I)=.0679*B(I,18)*DIAM
      RPS=RPM/60.
      DO 996 I=1,JC
      PXTBI(I)=PI*B(I,3)*B(I,5)
      PXTB(I)=PI*B(I,3)*B(I,8)
  996 CONTINUE
      EA1=(EAR*3.14159*DIA**2)/4.0
      AL=3.14159*0.7*B(7,5)
      AP=EA1*(1.067-0.229*AL)
      VA=VS*B(7,4)
      VR=SQRT(VA**2+(0.7*3.14159*RPS*DIA)**2)
      TC=2.0*B(6,2)/(RHO*AP*VR**2)
      SIGMA7=(64.4*HEAD)/VR**2
       IF(JPR.NE.2) GO TO    400
10042 FORMAT(1H )
       WRITE(6,77) PP1,PP3,PP2,PP5
   77  FORMAT(4X,*CPTI=*,1PE10.4,4X,*CPSI=*,1PE10.4,4X,*CTSI=*,1PE10.4,
     2  4X,*CTSI/CPSI=*,1PE10.4)
      WRITE(6,10042)
      WRITE(6,78)
   78  FORMAT(6X,* X*,8X,*TANBI*,7X,*TAN B*,9X,*G*,9X,*UT/2V*,7X,
     2  *UA/2V*,7X,*DCTSI*,7X,*DCPSI*,6X,*VR(M/SEC)*,5X,*CAVV*)
      DO 79 I=1,11
       VRSI=VSUBR(I)*ELF
   79 WRITE(6,6010) B(I,3),B(I,5),B(I,8),B(I,14),B(I,13),B(I,12),B(I,15)
     1 ,B(I,17),VRSI,B(I,19)
 6010 FORMAT(1P10E12.4)
      WRITE(6,10042)
       WRITE(6,6011) PP6,PP8,PP7,PP10
 6011  FORMAT(5X*CPT=*1PE10.4,5X*CPS=*1PE10.4,5X*CTS=*1PE10.4,6X,
     2  *CTS/CPS=*1PE10.4)
```

```
      WRITE(6,10042)
      WRITE(6,76)
   76  FORMAT(5X,* X*,8X,*CL*,6X,*ALI(DEG)*5X,*FM/C*,7X,*CD/CL*,7X,
     2  *F(X)*,5X,*LI(N/M)*,3X,*TETS(DEG)*,2X,*(C/RD)LE*,
     3  3X,*(C/RD)TE*,5X,*T/RD* )
      DO 6002 I=1,11
 6002 WRITE(6,20046)B(I,3),CCONE(I),CCTWO(I),CCTHR(I),CCFOR(I),FX(I),PLF
     1T(I),AZZ(I,38),AZZ(I,28),AZZ(I,29),AZZ(I,34)
20046 FORMAT(1PE10.3,1P10E11.3)
      WRITE(6,10042)
       SHR=THR*SWT
       STHR=ATHR*SWT
       WRITE(6,10044) PP11,PP12,ETHRUS,EWAKE,VK,SHR,VMS,STHR
      WRITE(6,6003)
 6003  FORMAT(1H1,4X,*X*,7X,*AREA(M2)*,4X,*XBAR(M)*,2X,*YBAR(M)*,5X,
     2 *IXO(M4)*,4X,*IYO(M4)*,4X,*MXO(N-M)*3X,*MYO(N-M)*,3X,*MTB(N-M)*,
     3  ,3X,*MOB(N-M)*,3X,*MAXSTRESS(PA)*)
  400  CONTINUE
      DO 122 I=1,7
      IF(I-1) 120,121,120
  121 SX(I)=B(I,3)
      GO TO 122
  120 SX(I)=B(I+1,3)
  122 CONTINUE
       IF(JPR.NE.2) GO TO    10091
      DO 124 I=1,7
       APR=EL2*AREA(I)
       XPR=ELI*XBAR(I)
       YPR=ELI*YBAR(I)
       XOI=EL4*AYEXO(I)
       YOI=EL4*AYEYO(I)
       XOM=SIM*EMXO(I)
       YOM=SIM*EMYO(I)
       TBM=SIM*EMTB(I)
       QBM=SIM*EMOB(I)
       STRM=SMX*STRMAX(I)
  124  WRITE(6,20046) SX(I),APR,XPR,YPR,XOI,YOI,XOM,YOM,TBM,QBM,STRM
      WRITE(6,10042)
      WRITE(6,10042)
      WRITE(6,6004)
 6004  FORMAT(5X*X*8X*RAKE*5X*PI XTANBI*3X*PI XTANB*)
      DO 6005 I=1,11
 6005 WRITE(6,6006)  B(I,3),RAK(I),PXTBI(I),PXTB(I)
 6006 FORMAT(1PE10.3,1P3E11.3)
10091 CONTINUE
      CTS(IK)=PP7
      CPS(IK)=PP8
      CPT(IK)=PP6
      CALL  WEIGHT(JC,SIGMA7,IPO,IPR,HUBDIM,IK,HUB)
      HUBSPAC=2.0*PI*X(1)*DIA*6.0*SIN(PITCH(1))/D(1,4,IK)
      BLASPAC=HUBSPAC-AX(1)*DIA*6.0
      FILSPAC=HUBSPAC-AX(1)*DIA*6.0*1.9
       IF(JPR.NE.2) GO TO    6902
      WRITE(6,998) TC,SIGMA7
       SBL=BLASPAC/DIA/12.
       SFI=FILSPAC/DIA/12.
       WRITE(6,994) SBL,SFI
```

```
998 FORMAT(/20X,*BURRILL THRUST COFFF    TC=*,E10.4//20X,*BURR:
   1TATION COEFF    SIGMA(0.7)=*,E10.4)
994  FORMAT(/20X,*CLEARANCE AT HUB BETWEEN BLADES/D=*,F13.8//,
   2  20X,*CLEARANCE AT HUB BETWEEN FILLETS/D=*,F13.8)
6907 CONTINUE
      IF(JPR.EQ.1) JPR=2
     DO 64 I=1,11
     AZZ(I,23)=AZZ(I,37)
     ABC(I,1)=B(I,3)
     ABC(I,2)=B(I,14)
     ABC(I,3)=AZZ(I,27)
     ABC(I,4)=AZZ(I,28)
     ABC(I,5)=AZZ(I,29)
     ABC(I,6)=AZZ(I,31)
     ABC(I,7)=B(I,12)
  64 ABC(I,8)=AZZ(I,34)
     ABC(2,9)=B(5,2)
     IF(IOCK.NE.0) GO TO 62
     IF(IK.NE.1) GO TO 62
     IF(NK.EQ.1) GO TO 63
     GO TO 62
  63 IF(NIT.EQ.1) GO TO 61
     GO TO 62
  61 BZ(1)=1.0
     BZ(2)=DIA
     BZ(3)=HEAD
     BZ(4)=XNM(1)/60.0
     BZ(5)=0.931
     BZ(6)=THR*2.0
     BZ(7)=VEL(1)*1.6878
     BZ(8)=RHO
     BZ(9)=EWAKF
     BZ(10)=BLA(1)
     BZ(11)=BZ(10)
     BZ(15)=CO
     BZ(16)=0.0
     BZ(17)=0.0
     BZ(18)=0.0
     DO 300 I=1,12
 300 BZ(I+99)=COM(I,1)
     IN1=6
     DO 301 IN=18,90,18
     IN1=IN1+1
     IF(IN.EQ.90) IN1=13
     DO 301 I=1,9
     IF(I-1) 302,303,302
 303 J=I
     GO TO 306
 302 IF(I-9) 305,304,305
 304 J=I+2
     GO TO 306
 305 J=I+1
 306 BZ(IN+I)=D(J,IN1,1)
 301 CONTINUE
     DO 307 IN=27,81,18
     IN9=IN+9
     DO 307 I=1,9
```

```
      BZ(IN+I)=BZ(IN9+I)
  307 CONTINUE
      BZ(10)=D(1,4,1)
      BZ(11)=D(1,4,2)
      DO 308 I=1,9
      IN=I+72
      IF(I-1) 309,310,309
  310 J=I
      GO TO 311
  309 IF(I-9) 312,313,312
  313 J=I+2
      GO TO 311
  312 J=I+1
  311 BZ(IN)=D(J,10,2)
  308 CONTINUE
      DO 5000 J=1,9
      IF(J.GT.1) GO TO 5010
      BZ(J+45)=GA11(J)
      GO TO 5000
 5010 IF(J.EQ.9) GO TO 5002
      BZ(J+45)=GA11(J+1)
      GO TO 5000
 5002 BZ(J+45)=GA11(J+2)
 5000 CONTINUE
      CALL OLD(BZ,IPO)
   62 CONTINUE
      D(10,2,2)=BZ(16)
      FAR=D(10,2,2)/D(10,2,1)
      AFR=D(10,2,1)/D(10,2,2)
      DO 320 I=1,JT
      DEX(I,3,1)=FAR*D(I,7,2)
      DEX(I,3,2)=AFR*D(I,7,1)
  320 CONTINUE
      IC=IC+1
      IF(IC) 17,17,20
   17 CONTINUE
      CALL FIELD(ABC,UA,UT,UR,IK,DEX,COM,IPO)
      IF(IC) 18,18,20
   18 DO 19 I=1,11
      UA1(I,IK)=UA(I)
      UT1(I,IK)=UT(I)
   19 UR1(I,IK)=UR(I)
      DO 326 I=1,11
      IF(DEX(I,3,1)-D(1,7,1)) 325,325,20
  325 UA1(I,1)=0.0
      UT1(I,1)=0.0
      UR1(I,1)=0.0
  326 CONTINUE
   20 CONTINUE
      UA1(I,1)=0.0
      UT1(I,1)=0.0
      UR1(I,1)=0.0
       IF(JPR.NE.3) GO TO    46
      IF(IC)46,95,46
   95 WRITE(6,106)
  106 FORMAT(1H1////50X,*INDUCED VELOCITIES*///33X,*R*,13X,*UA/VS*,11X,*
     1UR/VS*,11X,*UT/VS*/22X,*ON AFT*)
```

```
      DO 107 I=1,11
      WRITE(6,108) DEX(I,3,1),UA1(I,1),UR1(I,1),UT1(I,1)
  108 FORMAT(23X,4F16.4)
  107 CONTINUE
      WRITE(6,109)
  109 FORMAT(///22X,*ON FW)*)
      DO 110 I=1,11
      WRITE(6,108) DFX(I,3,2),UA1(I,2),UR1(I,2),UT1(I,2)
  110 CONTINUE
 5007 CONTINUE
   46  IF(JPR.EQ.0) JPP=1
      DO 111 I=1,11
      UA(I)=UA1(I,IK)
      UR(I)=UR1(I,IK)
  111 UT(I)=UT1(I,IK)
      IF(SHP) 81,81,69
   81 IVA=IVA+1
      IF(IVV-IVA) 96,70,70
   70 GO TO 10046
   69 IF(NTT.EQ.NXVV+1) GO TO 96
      IF(NT.NE.IDU-1) GO TO 97
   98 NF=NF+1
      IF(IK-1) 93,93,94
   93 FWDSHP(NF)=PP12
      GO TO 96
   94 NF=NF-1
      AFTSHP(NF)=PP12
      GO TO 96
   97 IF(NT.EQ.IDU) GO TO 98
   96 JN=1
      IF(JO) 71,72,71
   72 IK=2
      GO TO 73
   71 IK=1
   73 CONTINUE
      IF(JO) 74,75,74
   75 JO=1
      GO TO 80
   74 JO=0
   80 CONTINUE
10072 CONTINUE
      IF(SHP.EQ.0.0) GO TO 10073
      IF(NTT.NE.NXVV) GO TO 10073
      DO 99 I=1,NXVV
      B11(I)=(FWDSHP(I)+AFTSHP(I))/2.0
      VEL(I)=D(I,1,IK)
   99 B3(I)=VEL(I)
      S1=SHP
      CALL DISCOT (S1,S1,B11,B3,B3,-120,NXVV,0,S2)
      VEL1(1)=S2
      DO 154 I=1,NXVV
      B11(I)=VEL(I)
      EHP(I)=D(I,2,IK)
  154 B3(I)=EHP(I)
      S1=VEL1(1)
      CALL DISCOT (S1,S1,B11,B3,B3,-120,NXVV,0,S2)
      EHP(1)=S2
```

```
      VEL(1)=VEL1(1)
      IVV=1
      IK=1
      GO TO 105
10073 CONTINUE
      DR=(D(10,2,2)/D(10,2,1))**2
      CTST=CTS(1)+DR*CTS(2)
      CPST=CPS(1)+DR*CPS(2)
      CPTT=CPT(1)+DR*CPT(2)
      ETAP=CPTT/CPST
      ETAD=D(1,3,1)*CTST/CPST
      WRITE(6,992) CTST,CPST,ETAD
  992 FORMAT(1H1,10X,*PERFORMANCE OF SET OF CONTRAROTATING PROPELLERS*//
     1//2X,*CTS= *,F8.5//2X,*CPS= *,F8.5//2X,*ETAD= *,F8.5)
      STOP
      END
```

```
      SUBROUTINE SUB
      DIMENSION CHORD(38),THICKNS(38),CAMBER(38),PITCH(38),SKEWR(38)
     1,XI(38)
      COMMON/CWEIGHT/XI,CHORD,THICKNS,CAMBER,PITCH,SKEWR,DIAM,ZZ,DEN
     1 ,RAKE,SI,PI,PP7,PP8,PP9,PP11,FWAKE,VS,RPS,SIGMA,FAR,BT
      DIMENSION B(38,38),B1(181),B2(181),B3(181),B4(362),B5(362),B6(362)
     1,B7(181),B8(181),B9(181),B10(181),B11(181),B12(181), B13(181),B14(
     2181),B15(181),AZ(38,38),BH(38,38),C(38,38),CC(38,38),INDEX(38,3)
     3,A(38,72),BB(38,72)
      COMMON B,B1,B2,B3,B4,B5,B6,B7,B8,B9,B10,B11,B12,B13,B14,B15,AZ,BH,
     1C,CC,INDEX,A,BB
      COMMON IB,JB,JC,JD,JDD,JFF
      COMMON CL1(11)
      COMMON CCONE(11),CCTWO(11),CCTHR(11),CCFOR(11)
      COMMON PP1,PP2,PP3,PP4,PP5,PP6,PP10
10052 DO 10025 N=1,JC
      DO 20021 I=1,JC
      AAG=1./B(I,5)
      AAH=B(N,3)/B(I,3)*AAG
      AAD=ATAN(B(I,5))
      IF(AAH-AAG)10019,10018,10019
10018 B2(I)   =COS(AAD)
      B3(I)   =SIN(AAD)
      GO TO 20021
10019 S=1.+AAH**2
      T=SQRT(S)
      V=1.+AAG**2
      W=SQRT(V)
      AE=T-W
      U=EXP(AE)
      R=(((T-1.)/AAH*(AAG/(W-1.)))*U)**B(9,2)
      AC=1.5
      AD=.25
      X=(1./(2.*B(9,2)*AAG))*((V/S)**AD)
      Y=((9.*AAG**2)+2.)/(V**AC)+((3.*AAH **2-2.)/(S**AC))
      Z=1./(24.*B(9,2))*Y
      IF(AAH-AAG)10021,10021,10020
10020 AF=1.+1./(R-1.)
      AA=X*(1./(R-1.)-Z*ALOG(AF))
      B2(I)   =2.*B(9,2)**2*AAG*AAH*(1.-AAG/AAH)*AA
      B3(I)   =B(9,2)*(1.-AAG/AAH)*(1.+2.*B(9,2)*AAG *AA)
      GO TO 20021
10021 AG=1.+1./(1./R-1.)
      AB=-X*(1./(1./R-1.)+Z*ALOG(AG))
      B2(I)   =B(9,2)*AAG*(1.-AAH/AAG)*(1.-2.*B(9,2)*AAG*AB)
      B3(I)   =2.*B(9,2)**2*AAG*(1.-AAG/AAH)*AB
20021 CONTINUE
20024 FORMAT(9F12.4)
      IN=0
      DO 1 I=1,181,5
      IN=IN+1
1     B1(IN)=.5*(1.+B(1,3))-.5*(1.-B(1,3))*COS((FLOAT(I-1)/57.2957))
      DO 2 I=1,JC
      B11(I)=B(I,3)
      B12(I)=B2(I)
2     B13(I)=B3(I)
      DO 3 I=1,37
```

```
      S1=B1(I)
      CALL DISCOT(S1,S1,B11,B13,B13,-120,JC,0,S3)
3     B15(I)=S3
      DO 5 I=1,37
      S1=B1(I)
      CALL DISCOT(S1,S1,B11,B12,B12,-120,JC,0,S2)
5     B14(I)=S2
      DO 4 I=1,37
      B2(I)=B14(I)
4     B3(I)=B15(I)
      DO 10022 L=1,35
      N1=37+L
      N2=37-L
      B2(N1)=B2(N2)
10022 B3(N1)=B3(N2)
      C2=2./72.
      NP=72
      NH=36
      XNP=NP
      S=0.0
      SL=0.0
      DO 20 I=1,NP
      S=S+B2(I)
   20 SL=SL+B3(I)
      B4(1)=S/XNP
      B5(1)=SL/XNP
      DO 40 I=1,NH
      S=0.0
      SL=0.0
      S1=0.0
      SL1=0.0
      DO 30 J=1,NP
      S=S+B2(J)*BB(I,J)
      SL=SL+B3(J)*BB(I,J)
      S1=S1+B2(J)*A(I,J)
   30 SL1=SL1+B3(J)*A(I,J)
      I1=5*I+1
      B4(I1)=S*C2
      B5(I1)=SL*C2
      B4(I1+1)=S1*C2
   40 B5(I1+1)=SL1*C2
      B(1,9)=B4(1)
      B(1,10)=B5(1)
      JCM1=JC-1
      DO 10023 LK=1,35
      L=LK+1
      K=5*LK
      B(L,9)=B4(K+1)
10023 B(L,10)=B5(K+1)
      B(37,9)=B4(181)
      B(37,10)=B5(181)
      CPHI=((1.+B(1,3))-2.*B(N,3))/(1.-B(1,3))
      IF(ABS(CPHI)-1.) 20051,20051,20050
20050 CPHI=1.
20051 B(N,11)=ACOS(CPHI)
      B(1,11)=.0
      B(JC,11)=3.1415927
```

```
      CON3=3.1415927
      DO 10025 I=1,JC
      SMP=SIN(FLOAT(I)*B(N,11))
      CMP=COS(FLOAT(I)*B(N,11))
      IF(N-1)10027,10026,10027
10027 IF(N-JC)10028,10029,10028
10026 AZN=.0
      BZN=.0
      N2=I+1
      DO 20026 K=1,N2
      IF(K-JC)10070,10070,20026
10070 AZN=AZN+CON3*FLOAT(I)*B(K,9)
      BZN=BZN+CON3*FLOAT(I)*B(K,10)
20026 CONTINUE
      AZL=.0
      BZL=.0
      IF(N2-JC)10060,10030,10030
10060 N1=N2+1
      DO 20036 M=N1,JC
      L=M-1
      AZL=AZL+FLOAT(L)*B(M,9)*CON3
20036 BZL=BZL+FLOAT(L)*B(M,10)*CON3
      GO TO 10030
10029 AZN=.0
      BZN=.0
      N2=I+1
      DO 20029 K=1,N2
      CKP=COS(FLOAT(K-1)*B(N,11))
      IF(K-JC)10071,10071,20029
10071 AZN=AZN-CON3*CMP*FLOAT(I)*B(K,9)*CKP
      BZN=BZN-CON3*CMP*FLOAT(I)*B(K,10)*CKP
20029 CONTINUE
      AZL=.0
      BZL=.0
      IF(N2-JC)10061,10030,10030
10061 N1=N2+1
      DO 20039 M=N1,JC
      L=M-1
      CKP=COS(FLOAT(L)*B(N,11))
      AZL=AZL-CON3*CMP*FLOAT(L)*B(M,9)*CKP
20039 BZL=BZL-CON3*CMP*FLOAT(L)*B(M,10)*CKP
      GO TO 10030
10028 AZN=.0
      BZN=.0
      CON1=3.1415927/SIN(B(N,11))
      N2=I+1
      DO 20028 K=1,N2
      CKP=COS(FLOAT(K-1)*B(N,11))
      IF(K-JC)10072,10072,20028
10072 AZN=AZN+CON1*SMP*B(K,9)*CKP
      BZN=BZN+CON1*SMP*B(K,10)*CKP
20028 CONTINUE
      AZL=.0
      BZL=.0
      IF(N2-JC)10062,10030,10030
10062 N1=N2+1
      DO 20038 M=N1,JC
```

```
      L=M-1
      SKP=SIN(FLOAT(L)*B(N,11))
      AZL=AZL+CON1*CMP*B(M,9)*SKP
20038 BZL=BZL+CON1*CMP*B(M,10)*SKP
10030 AZ(I,N)=AZN+AZL
      BH(I,N)=BZN+BZL
10025 CONTINUE
      IF(B(1,1))20043,20043,10034
20043 CONTINUE
      DO 10031 I=1,JC
      CC(I,1)=(1.-B(1,3))*(B(I,5)/B(I,8)-1.)*B(I,4)
      DO 10031 J=1,JC
10031 C(I,J)=FLOAT(J)*(AZ(J,I)+B(I,5)*BH(J,I))
      B10(181)=JC
      CALL SIMEQ(JC,C,CC)
10034 DO 10035 I=1,JC
      B(I,12)=.0
      B(I,13)=.0
      B(I,14)=.0
      DO 10035J=1,JC
      IF(B(1,1))10036,10036,10037
10036 B(I,12)=B(I,12)+FLOAT(J)*CC(J,1)*AZ(J,I)/B(I,4)*(1./(1.-B(1,3)))
      B(I,13)=B(I,13)+FLOAT(J)*CC(J,1)*BH(J,I)/B(I,4)*(1./(1.-B(1,3)))
      B(I,14)=CC(J,1)*SIN(FLOAT(J)*B(I,11))/B(I,4)+B(I,14)
      GO TO 10035
10037 B(I,12)=B(I,12)+FLOAT(J)*B6(J)*AZ(J,I)/B(I,4)*(1./(1.-B(1,3)))
      B(I,13)=B(I,13)+FLOAT(J)*B6(J)*BH(J,I)/B(I,4)*(1./(1.-B(1,3)))
      B(I,14)=B(I,14)+B6(J)*SIN(FLOAT(J)*B(I,11))/B(I,4)
10035 CONTINUE
      B(JC,14)=.0
20001 DO 10038 I=1,JC
      B(I,15)=(B(I,14)*B(I,4)*(B(I,4)/B(I,3)-B(I,13)*B(I,4)))*4.*B(9,
     12)
      B(I,16)=B(I,15)*B(I,4)
      B(I,17)=(B(I,4)/B(I,8)*B(I,14)*B(I,4)*(B(I,4)+B(I,12)*B(I,4)))*4.
     1*B(9,2)
      BTT=ATAN(B(I,8))
      BTI=ATAN(B(I,5))
      B(I,18)=2.*3.1415927*B(I,14)*COS(BTI)/(1./B(I,8)-B(I,13))
      B(I,19)=64.31*(B(4,2)-B(I,3)*B(3,2)  /2.)*(SIN(BTT)/(B(I,4)*B(7,2)
     1*COS(BTI-BTT)))**2
      IF(I-1)9,9,6
6     IF(I-JC)10,9,9
9     B(I,20)=.0
      B(I,21)=.0
      GO TO 11
10    CONTINUE
      B(I,20)=(1.-B(I,7)*B(I,6)/B(I,18)*B(I,5))*B(I,15)
      B(I,21)=(1.+B(I,7)*B(I,6)/B(I,18)/B(I,5))*B(I,17)
11    CONTINUE
      B(I,22)=B(I,20)*B(I,4)
      B1(I)=B(I,3)
      B2(I)=B(I,15)
      B3(I)=B(I,16)
      B4(I)=B(I,17)
      B5(I)=B(I,18)
      B7(I)=B(I,19)
```

```
      B8(I)=B(I,20)
      B9(I)=B(I,21)
      B10(I)=B(I,22)
10038 CONTINUE
      PP1=SIMPUN(B1,B3,JC)
      PP2=SIMPUN(B1,B2,JC)
      PP3=SIMPUN(B1,B4,JC)
      PP4=PP1/PP3
      PP5=PP2/PP3
      PP6=SIMPUN(B1,B10,JC)
      PP7=SIMPUN(B1,B8,JC)
      PP8=SIMPUN(B1,B9,JC)
      PP9=PP6/PP8
      PP10=PP7/PP8
      DO 10039 I=1,JC
      JCI=JC+1-I
      DO 10040 L=1,JC
      X0=B(L,3)-B(I,3)
      IF(X0) 860,860,871
860   X0=0.0
      GO TO 861
871   CONTINUE
      X0=B(L,3)-B(I,3)
861   CONTINUE
      B2(L)=X0*B(L,20)
10040 B3(L)=X0/B(L,3)*B(L,21)
      IF(JCI-2)10041,10041,10059
10041 B(I,25)=.0
      B(I,26)=.0
      B(I,27)=.0
      B(I,28)=.0
      GO TO 10039
10059 B(I,25)=SIMPUN(B1,B2,JC )         *(B(4,2)*B(3,2)**3*3.1415927*B(7,2
     1)**2)/(16.*B(9,2))
      B(I,26)=SIMPUN(B1,B3,JC )         *B(8,2)*B(3,2)**2*B(7,2)**3/(16.*B
     1(5,2)*B(9,2))
      BTI=ATAN(B(I,5))
      SBI=SIN(BTI)
      CBI=COS(BTI)
      B(I,27)=B(I,25)*CBI+B(I,26)*SBI
      B(I,28)=B(I,25)*SBI-B(I,26)*CBI
10039 CONTINUE
      DO 206 I=1,JC
      B(I,12)=B(I,4)*B(I,12)
      B(I,13)=B(I,4)*B(I,13)
206   B(I,14)=B(I,4)*B(I,14)
20080 IF(JEF)20082,20082,10081
20082 B6(361)=-1.0
20081 CONTINUE
      IF(B6(361)) 10080,10080,10081
10080 CONTINUE
      B15(181)=PP10
      DO 10049 I=1,JC
      IF(B(I,6)) 702,702,703
702   CC1=0.0
      GO TO 704
703   CC1=B(I,18)/B(I,6)
```

```
704    CONTINUE
       CL1(I)=CC1
       CC2=1.54*CC1
       CC3=.0679*CC1
       IF(CC1) 701,700,701
700    CC4=0.0
       B(I,38)=CC4
       GO TO 52
701    CC4=B(I,7)/CC1
       B(I,38)=CC4
    52 CCONE(I)=CC1
       CCTWO(I)=CC2
       CCTHR(I)=CC3
10049  CCFOR(I)=CC4
10081  CONTINUE
       B5(362)=PP7
       B6(362)=PP8
20041  RETURN
       END
```

```
      SUBROUTINE SIMEQ(JC,C,CC)
      DIMENSION BH(38,38),A(38,38),B15(38),C(38,38),CC(38,38)
      MP1=JC
      MPC=MP1+1
      MPD=MP1
      DO 80 I=1,MP1
80    C(I,MPC)=-CC(I,1)
      DO 81 I=1,MP1
      DO 81 J=1,MPC
81    BH(I,J)=0.0
      DO 20 I=1,MP1
20    BH(I,1)=-C(1,I+1)/C(1,1)
      DO 21 I=1,MP1
      J=I+1
21    BH(I,J)=1.0
      K=2
93    IF(K-MP1) 92,92,94
92    CONTINUE
      DO 86 I=1,MPD
      DO 86 J=1,MPC
86    A(I,J)= C(K,J)*BH(I,J)
      DO 88 I=1,MPD
      AN=0.0
      DO 87 J=1,MPC
87    AN=AN+A(I,J)
88    B15(I)=AN
      MPD=MPD-1
      DO 89 I=1,MPD
      DO 89 J=1,MPC
89    CC(I,J)=-B15(I+1)/B15(1   )*BH(1   ,J)+BH(I+1,J)
      DO 90 I=1,MPD
      DO 90 J=1,MPC
90    BH(I,J)=CC(I,J)
      K=K+1
      GO TO 93
94    CONTINUE
      DO 99 J=1,MPC
99    CC(J,1)=CC(1,J)
1     FORMAT(1P6E12.4)
2     FORMAT(6F8.4)
      RETURN
      END
```

```
      SUBROUTINE DISCOT (XA,ZA,TABX,TABY,TABZ,NC,NY,NZ,ANS)
      DIMENSION TABX(1),TABY(1),TABZ(1),NPX(37),NPY(37),YY(37)
      CALL UNS (NC,IA,IDX,IDZ,IMS)
      IF (NZ-1)    5,5,10
    5 CALL DISSER (XA,TABX,1,NY,IDX,NN)
      NNN=IDX+1
      CALL LAGRAN (XA,TABX(NN),TABY(NN),NNN,ANS)
      GOTO 70
   10 ZARG=ZA
      IP1X=IDX+1
      IP1Z=IDZ+1
      IF (IA)    15,25,15
   15 IF (ZARG-TABZ(NZ))    25,25,20
   20 ZARG=TABZ(NZ)
   25 CALL DISSER (ZARG,TABZ,1,NZ,IDZ,NPZ)
      NX=NY/NZ
      NPZL=NPZ+IDZ
      I=1
      IF (IMS)    30,30,40
   30 CALL DISSER (XA,TABX,1,NX,IDX,NPX)
      DO 35 JJ=NPZ,NPZL
      NPY(I)=(JJ-1)*NX+NPX(1)
      NPX(I)=NPX(1)
   35 I=I+1
      GOTO 50
   40 DO 45 JJ=NPZ,NPZL
      IS=(JJ-1)*NX+1
      CALL DISSER (XA,TABX,IS,NX,IDX,NPX(I))
      NPY(I)=NPX(I)
   45 I=I+1
   50 DO 55 I=1,IP1Z
      NLOC=NPX(I)
      NLOCY=NPY(I)
   55 CALL LAGRAN (XA,TABX(NLOC),TABY(NLOCY),IP1X,YY(I))
      CALL LAGRAN (ZARG,TABZ(NPZ),YY,IP1Z,ANS)
   70 RETURN
      END
```

```
      SUBROUTINE UNS (IC,IA,IDX,IDZ,IMS)
      IF (IC)    5,5,10
    5 IMS=1
      NC=-IC
      GOTO 15
   10 IMS=0
      NC=IC
   15 IF (NC-100)    20,25,25
   20 IA=0
      GOTO 30
   25 IA=1
      NC=NC-100
   30 IDX=NC/10
      IDZ=NC-IDX*10
      RETURN
      END
```

```
      SUBROUTINE LAGRAN (XA,X,Y,N,ANS)
      DIMENSION X(1),Y(1)
      SUM=0.0
      DO 3 I=1,N
      PROD=Y(I)
      DO 2 J=1,N
      A=X(I)-X(J)
      IF (A)    1,2,1
    1 B=(XA-X(J))/A
      PROD=PROD*B
    2 CONTINUE
    3 SUM=SUM+PROD
      ANS=SUM
      RETURN
      END
```

```
      SUBROUTINE DISSER (XA,TAB,I,NX,ID,NPX)
      DIMENSION TAB(1)
      NPT=ID+1
      NPB=NPT/2
      NPU=NPT-NPB
      IF (NX-NPT)    10,5,10
    5 NPX=I
      RETURN
   10 NLOW=I+NPB
      NUPP=I+NX-(NPU+1)
      DO 15 II=NLOW,NUPP
      NLOC=II
      IF (TAB(II)-XA)    15,20,20
   15 CONTINUE
      NPX=NUPP-NPB+1
      RETURN
   20 NL=NLOC-NPB
      NU=NL+ID
      DO 25 JJ=NL,NU
      NDIS=JJ
      IF (TAB(JJ)-TAB(JJ+1))    25,30,25
   25 CONTINUE
      NPX=NL
      RETURN
   30 IF (TAB(NDIS)-XA)    40,35,35
   35 NPX=NDIS-ID
      RETURN
   40 NPX=NDIS+1
      RETURN
      END
```

```
      FUNCTION SIMPUN(X,Y,N)
C     FORTRAN IV FUNCTION FOR SIMPSONS RULE INTEGRATION
C      ARBITRARY NO. AND LENGTH INTERVALS K.MEALS NSRDC CODE 842 10-5-67
      DIMENSION X( 2),Y( 2)
      IF(N-2) 7, 5,4
    5 S=(Y(1)+Y(2))*(X(2)-X(1))/2.
      GO TO 6
    4 M=N-1
    8 IF(M-2) 9,10,11
   11 M=M-2
      GO TO 8
    9 S=(X(2)-X(1))/6.*(Y(1)*(3.-(X(2)-X(1))/(X(3)-X(1)))+Y(2)*(3.+(X(2)
     1-X(1))/(X(3)-X(2)))-Y(3)*(((X(2)-X(1))**2)/((X(3)-X(1))*(X(3)-X(2)
     2))))
      L=3
      GO TO 12
   10 S=0.
      L=2
   12 M=N-1
      DO 1 K=L,M,2
      IF(ABS(X(K-1)-X(1)).GE.ABS(X(K)-X(1))) GO TO 3
      IF(ABS(X(K+1)-X(1)).GT.ABS(X(K)-X(1))) GO TO 1
    3 WRITE (6,2) K, X(K)
    2 FORMAT(23HONON MONOTONE X SIMPUN   I4,1PE12.4)
    7 S=0.
      GO TO 6
    1 S=S+(X(K+1)-X(K-1))/6.*(Y(K-1)*(3.-(X(K+1)-X(K-1))/(X(K)-X(K-1)))+
     1(Y(K)*(1.+(X(K+1)-X(K-1))/(X(K)-X(K-1))+(X(K)-X(K-1))/(X(K+1)-X(K)
     1))+(Y(K+1)*(2.-(X(K)-X(K-1))/(X(K+1)-X(K))))))
    6 SIMPUN=S
      RETURN
      END
```

```
      SUBROUTINE STRESS(AZZ,AREA,XBAR,YBAR,AYEXO,AYEYO,EMXO,EMYO,EMTB,EM
     1QB,STRMAX)
      DIMENSION CHORD(38),THICKNS(38),CAMBER(38),PITCH(38),SKEWR(38)
     1,XI(38),BT(11)
      COMMON/CWEIGHT/XI,CHORD,THICKNS,CAMBER,PITCH,SKEWR,DIAM,ZZ,DEN
     1 ,RAKE,SI,PI,PP7,PP8,PP9,PP11,EWAKE,VS,RPS,SIGMA,EAR,BT
      DIMENSION AZZ(38,33)
      DIMENSION AREA(7),XBAR(7),YBAR(7),AYEXO(7),AYEYO(7),EMXO(7),EMYO(7
     1),EMTB(7),EMQB(7),STRMAX(7)
C * * * * * * * * * * *   ALL PROGRAM CONVERTING WAS DONE BY BOB MCCALLEY
C * * * * * * * * * * *   JOHN METZ ,  AT GLENN ENGINEERING SERVICES, INC.
C * * * * * * * * * * *   ROCKVILLE, MARYLAND  20856   PHONE 427-3830
C
C * * * * * * * * * * * VERSION VA20 IS A MODIFICATION OF HY-74
CC * * * * * * * * * * * WHICH APPROXIMATES THE EFFECT OF SKEW.
C * * * * * * * * * * * MODIFICATION BY D.T.VALENTINE
C * * * * * * * * * * * CODE 544    AUGUST, 1970.
C
C     PROPELLER STRESS CALCULATION PROGRAM  VA20
C
C * * * * * SIMPLE BEAM APPROXIMATION INCLUDING
C * * * * * BENDING, CENTRIFUGAL AND TORSIONAL FORCES.
C
C * * * * * * * * * * * * * * * *  PROGRAM TYPE A * * * * * * * * * * * * *
C * * * * * * * *  THIS PROGRAM READS IN THE NEW TYPE DATA CARDS. * * * *
C  THIS AREA RESERVES COMPUTER STORAGE FOR ALL ARRAYS USED IN THE PROGRA
      DIMENSION XE(20)
      DIMENSION HA(20),HA1(20),PHI(20),PHI2(20),XU1(20),T1(20),Q1(20),CP
     1HI(20),SPHI(20),X4(20),AE(20),BF(20),PE(20)
      DIMENSION   A(13),B(13),C(13),D(13),E(13),F(13),G(13),H(13),O(13),
     XP(13),Q(13),R(13),S(13),T(13),U(13),V(13),W(13),X(13),Y(13),Z(13)
      DIMENSION R1(7,16), S1(7,16)
      DIMENSION CENTST (7), CENTMO (7)
      DIMENSION FMX(7),TX(7),FMMX(13),YTX(13),SKEW(13),XU(10)
      DIMENSION VOL(7),CENT4(7),A1(7),A2(7),X2BAR(7),CENTS2(7),B2(13),
     X          F5(13),P2(13),O2(13),AA(10),BB(10),CENT42(7),CENTMS(7),
     X          TSKEW1(7),TSKEW2(7),ASKEW1(7),ASKEW2(7)
      DIMENSION V2(13),D2(13),E2(13)
      DIMENSION  ALPHA(7)
      DIMENSION XMT(10),XL(10),XM(10),XT(10),STM(10),STLT(10)
C  SET UP CONSTANTS USED IN PROGRAM CONPUTATIONS.
      W( 1)=1.
      W( 2)=4.
      W( 3)=3.
      W( 4)=8.
      W( 5)=4.
      W( 6)=8.
      W( 7)=4.
      W( 8)=8.
      W( 9)=4.
      W(10)=8.
      W(11)=3.
      W(12)=4.
      W(13)=1.
      GRAV = 32.14
C - - - - - - - - - - - -  INPUT DATA DESCRIPTIONS - - - - - - - - - - -
C                M = TOTAL NUMBER OF PROPELLER RUNS TO BE MADE IN THIS BAT
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C                   PUNCHED IN COL. 1 AND 2 OF INPUT CARD.
C               PR, ID = PROPELLER ID CODE.  ANY ALPHNUMERIC CHARACTERS.
C                        PUNCHED IN COL. 1 THRU 12 OF CARD.
C               DA, TE = DATE OF RUN. ANY ORDER. PUNCHED IN COL. 13 THRU
C               ZZ= NUMBER OF PROPELLER BLADES. PUNCHED IN COL. 25 THRU 2
C                   YOU MUST PUNCH A DECIMAL POINT WITH THE VALUE.
C               VS = SPEED ADVANCE IN FEET PER SECOND. PUNCHED IN COL. 29
C                    36.  A DECIMAL POINT MUST ALSO BE PUNCHED WITH VALUE
C               DEN = DENSITY OF PROP. IN LBS. PER CUBIC FEET.
C                     PUNCHED IN COL. 37 THRU 41 INCLUDING DECIMAL POINT.
C               DIAM = DIAMETER OF PROP. IN FEET.     PUNCHED IN COL. 42
C                      INCLUDING A DECIMAL POINT.
C               RAKE = RAKE OF THE PROP. IN DEGREES.  PUNCHED IN COL. 46
C                      49 INCLUDING A DECIMAL POINT.
C               VEL = VELOCITY OF PROP. IN REVOLUTIONS PER MIN.
C                     PUNCHED IN COL. 50 THRU 56 INCLUDING DECIMAL POINT.
C               O(I) = LOCAL NONVISCOUS THRUST COEFFICIENT AT XU(I).
C                      PUNCHED IN COL. 1 THRU 9 INCLUDING DECIMAL POINT.
C               T(I) = TANGENT OF THE HYDRODYNAMIC PITCH ANGLE AT XU(I).
C                      PUNCHED IN COL. 10 THRU 18 INCLUDING DECIMAL POINT
C               E(I) = DRAG-LIFT RATIO AT XU(I). PUNCHED IN COL. 19 THRU
C                      INCLUDING A DECIMAL POINT.
C               P(I) = PITCH TO DIAMETER RATIO AT XU(I).
C                      PUNCHED IN COL. 28 THRU 36 INCLUDING DECIMAL POINT
C               C(I) = CORD LENGTH IN INCHES. PUNCHED IN COL. 37 THRU 45
C                      INCLUDING A DECIMAL POINT.
C               SKEW(I) = SKEW VALUE IN INCHES FROM LEADING EDGE TO THE
C                         REFERENCE EDGE . ALONG THE HELIX.
                                         PUNCHED IN COL. 46 THRU 52. PO
                XU(I) = VALUE OF -X- AS WE USE IT IN PROP REFERENCES.
                        PUNCHED IN COL. 55 THRU 61 , INCLUDING DECIMAL PO
C               FMX(I) = MAX CAMBER AT VALUE OF U(I).
C                        PUNCHED IN COL. 1 THRU 7 INCLUDING DECIMAL POINT
C               TX(I) = MAX THICKNESS AT VALUE OF U(I).
C                       PUNCHED IN COL. 8 THRU 16 INCLUDING DECIMAL POINT
C               FMMX(I) = CAMBER / MAX CAMBER VALUE AT U(I).
C                         PUNCHED IN COL. 28 THRU 34 INCLUDING DECIMAL PO
C               YTX(I) = ONE HALF THICKNESS / MAX THICKNESS AT VALUE OF U
C                        PUNCHED IN COL. 37 THRU 43 INCLUDING DECIMAL POI
C               U(I) = VALUE OF X SUB L USED IN PROP REFERENCES.
C                      PUNCHED IN COL. 50 THRU 56 INCLUDING DECIMAL POINT
C**********************      PROGRAM NAMES DEFINED BELOW      ***********
                CENTST  =  STRESS DUE TO CENTRIFUGAL FORCE.
                CENTMO  =  MOMENT DUE TO RAKE , THAT IS ASKEW2 - ASKEW1.
                CENTMS  =  MOMENT DUE TO SKEW THAT IS TSKEW2 - TSKEW1 .
                CENT42  =  COMPONENT OF CENT4.
                CENT4   =  CENTRIFUGAL FORCE.
                X2BAR  =  CENTROID IN FEET.
                TSKEW1  =  TRANSVERSE SKEW AT POINT OF INTERESTS. 0.2,0.3
                TSKEW2  =  TRANSVERSE SKEW AT CENTROID, X2BAR, IN INCHES.
C               ASKEW1  =  LONGITUDIAL SKEW AT POINT OF INTERESTS. (RAKE+
C               ASKEW2  =  LONGITUDIAL SKEW AT CENTROID, X2BAR, IN INCHES
C                          ( RAKE + SKEW ).
C               VOL  =  VOLUMNE IN CUBIC FEET.
C************************************************************************
C
C   DURING THE TIME OF PROGRAM CONVERSION WE USED VARIABLE NAMES THAT WE
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C   TOO LONG FOR USE ON THE IBM 7090 FORTRAN SYSTEM, THEREFORE WE HAD TO
C   SHORTEN THEM TO NO MORE THAN SIX CHARACTERS LONG.  THE FOLLOWING IS
C   OF THSES SHORTENED NAMES ..........
C
C                     CENTFOR  - CUT TO - CENT4
C                     CENTST2 - CUT TO - CENTS2
C                     CENTFOR2 - CUT TO - CENT42
C                     CENTMOS - CUT TO - CENTMS
C                     LSKEW1  -     TO - ASKEW1
C                     LSKEW2  -     TO - ASKEW2
C
C*******************************************************************
C      ****************************** READ  INPUT ***************************
C  ONE CARD IS READ TO SET UP MAIN LOOP AS TO THE NUMBER OF PROP STUDIES
      NN=1
   18 FORMAT(8F9.6)
      ZZ=AZZ(9,2)
      VS=AZZ(7,2)
      DIAM=AZZ(3,2)
      DIA=DIAM
      VEL=60.0*AZZ(5,2)
      ISEC=0
      AZZ(10,20)=0.0
      AZZ(10,21)=BT(11)
      AZZ(10,22)=0.0
      DO 1000 I=1,10
      D(I)=AZZ(I,20)
      T(I)=AZZ(I,21)
      E(I)=AZZ(I,22)
      P(I)=0.0
      C(I)=AZZ(I,23)*DIA*12.0
      SKEW(I)=C(I)/2.0-AZZ(I,24)*DIA*12.0/2.0
 1000 XU(I)=AZZ(I,19)
      DO 30 J=2,7
   30 AZZ(J,25)=AZZ(J+1,25)
      DO 1001 I=1,7
      FMX(I)=0.0
 1001 TX(I)=AZZ(I,25)*DIA*12.0
      FMMX(1)=.0000
      FMMX(2)=.2712
      FMMX(3)=.4482
      FMMX(4)=.6993
      FMMX(5)=.8635
      FMMX(6)=.9615
      FMMX(7)=1.000
      FMMX(8)=.9786
      FMMX(9)=.8592
      FMMX(10)=.7027
      FMMX(11)=.3586
      FMMX(12)=.1713
      FMMX(13)=.0000
      YTX(1)=.0000
      YTX(2)=.2066
      YTX(3)=.2907
      YTX(4)=.4000
      YTX(5)=.4637
      YTX(6)=.4952
```

```
      YTX(7)=.4962
      YTX(8)=.4653
      YTX(9)=.4035
      YTX(10)=.3110
      YTX(11)=.1877
      YTX(12)=.1143
      YTX(13)=.0333
      IN=0
      U(1)=0.0
      U(2)=0.05
      DO 1002 I=3,11
      IN=IN+1
 1002 U(I)=0.1*FLOAT(IN)
      U(12)=0.95
      U(13)=1.0
   25 DO 50 I=1,7
      DO 60  J=1,13
      R1(I,J) =  (FMMX(J)*FMX(I)-YTX(J)*TX(I))  /C(I)
      S1(I,J) =  (FMMX(J)*FMX(I)+YTX(J)*TX(I))  /C(I)
   60 CONTINUE
   50 CONTINUE
C  CALCULATE THE VALUE OF F1 FROM INPUT VALUES.
   26 F1=1.9905*(DIAM/2.0)**3*VS**2*PI*6.0/ZZ
      FF1=F1
      DO 215 I=1,10
   52 P(I) = T(I)*PI*XU(I)
  215 CONTINUE
C     ******************************** ****** COMPUTE ****************************************
C  CALCULATIONS FOR CONSTANTS USED IN DETERMINATION OF TORQUE AND THRUST
C  CALCULATIONS OF BENDING MOMENTS FROM THRUST AND TORQUE.
      DO 360 I5=1,2
      F1=FF1
      RAD1=DIAM*0.5*12.0
      IF(I5-2)55,56,56
   55 DO 210 I=1,10
      PE(I)=P(I)
      A(I)=D(I)*(1.-E(I)*T(I))
      AE(I)=A(I)
      B(I)=D(I)*(E(I)+T(I))
      BE(I)=B(I)
      PHI(I)=ATAN(T(I))
      CPHI(I)=COS(PHI(I))
      SPHI(I)=SIN(PHI(I))
      HA(I)=(SKEW(I))*(CPHI(I)/(RAD1*XU(I)))
      XU1(I)=XU(I)*COS(HA(I))
      HA1(I)=C(I)/2.
  210 IF(SKEW(I).EQ.HA1(I)) XU1(I)=XU(I)
      GO TO 58
   56 DO 57 I=1,10
      P(I)=PE(I)
      A(I)=AE(I)
   57 B(I)=BE(I)
   58 F1=F1/60.0
      DO 69 I=1,7
      I1=I
      IF(I5-2)62,63,63
   62 X0=XU1(I)
```

```
      GO TO 64
   63 XO=XU(I)
   64 I3=0
      DO 68 I2=I1,10
      I3=I3+1
      IF(I5-2)65,66,66
   65 X4(I3)=(XU1(I2)-XO)
      XE(I3)=XU(I2)
      GO TO 67
   66 X4(I3)=(XU(I2)-XO)
      XE(I3)=XU(I2)
   67 T1(I3)=X4(I3)*A(I2)
   68 Q1(I3)=X4(I3)*B(I2)
      T(I)=SIMPUN(XE,T1,I3)
      Q(I)=SIMPUN(XE,Q1,I3)
      T(I)=T(I)*FF1
   69 Q(I)=Q(I)*FF1
C
C  LOOP WHICH APPROXIMATES STRESS DUE TO TORSION RESULTING
C    FROM SKEW
C     XT(I) = LIFT FORCE ,  XMT(I) = MOMENT DUE TO LIFT
C
      DO 111 I=1,7
      IF(I5-2)820,830,830
  820 XMT(I)=0.00
      XK=1.9905*(DIAM/2.0)**2.*VS**2.*PI/(2.0*ZZ)
      XA=C(I)/2.0
      XB=TX(I)/2.0
      DO 222 J=I,9
      XL(J)=ABS(SKEW(J)-.45*C(J))
      XL(J)=XL(J)-ABS(SKEW(I)-.5*C(I))
      XT(J)=(A(J)*0.1*XK)/(COS(PHI(J)+E(J)))
      XM(J)=XT(J)*XL(J)
      XMT(I)=XMT(I)+XM(J)
  222 CONTINUE
      STM(I)=XMT(I)*2.0/(PI*XA*XB**2.)
      STLT(I)=XMT(I)*2.0/(PI*XB*XA**2.0)
      GO TO 840
  830 STM(I)=0.00
      STLT(I)=0.00
840   CONTINUE
  111 CONTINUE
  550 FORMAT(1H0,29X,1HX,10X,4HTAUM,12X,5HTAULE,10X,7HM SUB T)
  500 FORMAT(1H,20X,4F18.6)
  600 FORMAT(1H1,50X,32HSHEARING STRESSES DUE TO TORSION)
C
C
C  LOOP WHICH CALCULATES AREA (A) OF SECTIONS.
      DO 230 I=1,7
      A(I)=0.0
      DO 230 J=1,13
      R(J)=R1(I,J)
      S(J)=S1(I,J)
  230 A(I)=A(I)+C(I)**2*(S(J)   -R(J)    )*H(J)          / 60.
C  LOOP WHICH CALCULATES VOL. OF SECTIONS.
      VOLTOT=0.0
      DO 241 I=1,6
```

```
      IF(I.EQ.1) U(I+3)=XU(I)
  238 VOL(I)=A(I)*(U(I+4)-U(I+3))*DIAM/288.0
  241 VOLTOT=VOLTOT+VOL(I)
  242 VOL(7)=A(7)*(1.0-U(10))*DIAM/ 576.0
  243 VOLTOT=VOLTOT+VOL(7)
C  LOOP WHICH CALCULATES CENTRIFUGAL FORCE AND STRESS.
      IF(I5-2)244,246,246
  244 DO 245 I=1,6
  245 A1(I)=XU1(I)+((XU1(I+1)-XU1(I))/2.0)
      A1(7)=XU1(7)+((XU1(10)-XU1(7))/2.0)
      GO TO 268
  246 DO 247 I=1,6
  247 A1(I)=XU(I)+((XU(I+1)-XU(I))/2.0)
      A1(7)=XU(7)+((XU(10)-XU(7))/2.0)
C  LOOP TO TRANSFER CONSTANTS FOR DETERMINING X2BAR.
  248 DO 236 I=1,7
      X2BAR(I) = 0.0
  236 A2(I) = A1(I) * VOL(I)
C  LOOP TO CALCULATE RADIAL CENTROID ( X2BAR ).
      DO 251 I=1,7
      X2BAR(I) =(  (A2(1)+A2(2)+A2(3)+A2(4)+A2(5)+A2(6)+A2(7)) / VOLTOT )
     X            * (DIAM/2.0)
      A2(I) = 0.0
C  UNCORRECTED FORCE AND STRESS FOR OUTPUT OF ANSWERS WITHOUT THE EFFECT
C  RAKE AND SKEW TAKEN INTO CONSIDERATION.
  264 CENT4(I) = DEN*4.0*PI**2*VEL**2*VOLTOT*X2BAR(I)/(3600.0*GRAV)
      CENTST(I) = CENT4(I) / A(I)
  251 VOLTOT = VOLTOT - VOL(I)
C  LOOKING AT THE EFFECTS OF RAKE AND SKEW IN THE PROPELLER.
      DO 263 I=1,10
      IF(I.EQ.1) U(I+3)=XU(I)
      AA(I) = PI*U(I+3)
  263 BB(I) = SQRT(AA(I)**2+P(I)**2)
      DO 267 I=1,7
      TSKEW1(I) = (C(I)/2.0 - SKEW(I)) * AA(I)/BB(I)
      KK = 1
  146 IF(X2BAR(I)-U(KK+3)*DIAM/2.0) 149,149,151
  151 KK= KK+1
      IF(KK-10)146,149,149
  149 TSKEW2(I) = (C(KK)/2.0 - SKEW(KK)) * AA(KK)/BB(KK)
      ALPHIA(I)=ATAN(TSKEW2(I)/(X2BAR(I) * 12.0) )
      CENT42(I) = CENT4(I)*COS(ALPHIA(I))
      CENTMS(I) = CENT42(I)*(TSKEW2(I) - TSKEW1(I))
      CENTS2(I) = CENT42(I) / A(I)
      ASKEW1(I)=(TSKEW1(I)*P(I)/AA(I)) + (U(I+3)*DIAM*6.0*
     X              TAN(RAKE*PI/180.0))
      ASKEW2(I)=(TSKEW2(I)*P(I)/AA(I)) + (U(KK+3)*DIAM*6.0*
     X               TAN(RAKE*PI/180.0))
  267 CENTMO(I) = CENT42(I) * ( ASKEW2(I) - ASKEW1(I) )
C  LOOP TO CALCULATE RESULT AND MOMENTS FOR BOTH ANSWER PAGES.
      DO 281 I=1,7
      D(I) = ((T(I)+CENTMO(I))*AA(I)+(Q(I)-CENTMS(I))*P(I))/BB(I)
      E(I)=((T(I)+CENTMO(I))*P(I)-(Q(I)-CENTMS(I))*AA(I))/BB(I)
      D2(I)=(T(I)*AA(I)+Q(I)*P(I)) / BB(I)
  281 E2(I)=(T(I)*P(I)-Q(I)*AA(I)) / BB(I)
C  PROGRAM CONTINUES.
      DO 350 I=1,7
```

```
      X(I)=0.0
      Y(I)=0.0
      DO 240 J=1,13
      R(J) = R1(I,J)
      S(J) = S1(I,J)
      X(I)=X(I)+C(I)**3*(S(J)    -R(J)    )*W(J)*U(J)    / 60./A(I)
  240 Y(I)=Y(I)+C(I)**3*(S(J)**2-R(J)**2)*W(J)          /120./A(I)
      G(I)=0.0
      H(I)=0.0
      DO 250 J=1,13
       G(I)=G(I)+C(I)**4*(S(J)**3-R(J)**3)*W(J)/180.
  250 H(I)=H(I)+C(I)**4*(S(J)    -R(J)    )*W(J)*U(J)**2/ 60.
      G(I)=G(I)-ABS(A(I))*Y(I)**2
      H(I)=H(I)-ABS(A(I))*X(I)**2
       F2=S(1)
      DO 270 J=2,13
      IF (F2-S(J)) 260, 270, 270
  260  F2=S(J)
  270 K=0
      DO 290 J=1,13
      IF (F2-S(J)) 330, 280, 290
  280  K=K+1
       Z(K)=U(J)
  290 K=K
      DO 300 L=1,K
      B(L)=((C(I)*Z(L)-X(I))*E(I))/H(I)-((C(I)*F2-Y(I))*D(I))/G(I)
     X+CENTS2(I)
      B2(L)=((C(I)*Z(L)-X(I))*E2(I))/H(I)-((C(I)*F2-Y(I))*D2(I))/G(I)+
     X  CENTST(I)
       V2(L)=ABS(B2(L))
  300 V(L)=ABS(B(L))
      F3=V(1)
      F4 = V2(1)
      F(I)=B(1)
      F5(I) = B2(1)
      DO 320 L=1,K
      F(I)=V(L)
  320 F5(I)=V2(L)
      GO TO 340
  330 F(I)=0.0
      F5(I) = 0.0
  340 P(I)=-X(I)*E(I)/H(I)-(C(I)*S(1)-Y(I))*D(I)/G(I)+CENTS2 (I)
      P2(I)=-X(I)*E2(I)/H(I)-(C(I)*S(1)-Y(I))*D2(I)/G(I)+CENTST(I)
      O2(I)=(C(I)-X(I))*E2(I)/H(I)-(-Y(I))*D2(I)/G(I)+CENTST(I)
  350 O(I)=(C(I)-X(I))*E(I)/H(I)-(-Y(I))*D(I)/G(I)+CENTS2 (I)
      DO 100 I=1,7
      AREA(I)=A(I)
      XBAR(I)=X(I)
      YBAR(I)=Y(I)
      AYEXO(I)=G(I)
      AYEYO(I)=H(I)
      EMXO(I)=O(I)
      EMYO(I)=F(I)
      STRMAX(I)=AZZ(I,11)
      EMTB(I)=T(I)
  100 EMOB(I)=Q(I)
      IF(I5-2) 351,352,352
```

```
351    CONTINUE
       CALL PFASTR (F,P,O,STM,STLT,AZZ)
       GO TO 360
   352 DUMMY=DUMMY
       NN = NN+1
   360 NN=NN+1
       RETURN
        END
```

```
       SUBROUTINE PRNSTR (XX,YY,ZZ,S1,S2,AZZ)
       DIMENSION AZZ(38,38)
       DIMENSION XX(10),YY(10),ZZ(10),S1(10),S2(10)
C
C      CALCULATION OF PRINCIPLE STRESSES
C      DUE TO TORSION AND BENDING.
C
       DIMENSION XI2(10),XI3(10)
       DO 333 K=1,7
       XI2(K)=-S1(K)*S1(K)
       XI3(K)=-S2(K)*S2(K)
   333 CONTINUE
       XXX=0.1
       DO 444 L=1,7
       XXX=XXX+0.1
       DO 555 M=1,3
       IF(M-2)72,22,33
    72 XI1=XX(L)
       DD=(ABS(XI1))**2.0
       XD=DD-4.*XI2(L)
       CC=(ABS(XD))**.5
       GO TO 44
    22 XI1=YY(L)
       GO TO 66
    33 XI1=ZZ(L)
    66 DD=(ABS(XI1))**2.0
       XD=DD-4.*XI3(L)
       CC=(ABS(XD))**.5
    44 SIGMA1=(XI1+CC)/2.0
       SIGMA2=(XI1-CC)/2.0
       AZZ(L,M)=XXX
       AZZ(L,M+10)=SIGMA1
555    AZZ(L,M+20)=SIGMA2
   444 CONTINUE
   700 FORMAT(1H,20X,F12.2,6X,2F20.6)
   850 FORMAT(1H0,33X,1HX,12X,6HSIGMA1,10X,6HSIGMA2)
   860 FORMAT(1H0,2X,99HSTRESSES AT EACH X STATION ARE GIVEN IN THE FOLLO
      XWING ORDER* MIDCHORD, LEADING EDGE, TRAILING EDGE. )
       RETURN
       END
```

```
      SUBROUTINE WEIGHT(JC,SIGMA7,IPO,IPR,HUBDIM,IK,HUB)
C        WEIGHT COMPUTES THE WEIGHT AND CENTER OF GRAVITY.  THE VALUES F
C        CHORD, THICKNS, CAMBER, PITCH AND SKEWR COME FROM GMAIN.  DIAM,
C        DEN, RAKE AND PI ARE SET IN STRESS.  OTHER VALUES ARE COMPUTED
C        MAKING CERTAIN ASSUMPTIONS.

       COMMON /WRT/ JPR
      COMMON/CWEIGHT/X,CHORD,THICKNS,CAMBER,PITCH,SKEWR,DIAM,ZZ,DEN,RAKE
     1,SI
     1,PI,CTS,CPS,EP,PC,WAKE,VS,RPS,SIGMA,EAR
      DIMENSION CHORD(38),THICKNS(38),CAMBER(38),PITCH(38),SKEWR(38)
     1,X(38)
      DIMENSICN DISTHF(38),A(38)
      DIMENSION R(9),PMT(9)
      DIMENSICN HUBDIM(6,2)
      DATA CNSTNT1,CNSTNT2,CNSTNT3/.3581,.8071,.0238/

C        ****VALUES COMPUTED AND DATA OUTPUT****
C        THE HUB DIAMETER IS ASSUMED TO BE THE DIAMETER TO THE FIRST RAD
C        RATIC TO BE CONSIDERED AND THE HUB ASSUMED TO BE CYLINDRICAL.
      HUBDIAM=X(1)*DIAM
C        THE HUB LENGTH IS ASSUMED TO EQUAL THE HUB DIAMETER AND THE DIS
C        THE REFERENCE LINE FROM THE HUB FACE IS TAKEN AS HALF THE HUB L
      DISREFL=HUBDIAM/2.
C        INPUT DATA AND ASSUMED DATA WRITTEN OUT.
      HUBLEN=HUBDIAM
      IF(HUB.EQ.0.) GO TO 50
      FWDDIAM=HUBDIM(1,IK)
      AFTDIAM=HUBDIM(2,IK)
      HUBLEN=HUBDIM(3,IK)
      FDBORE=HUBDIM(4,IK)
      ADBORE=HUBDIM(5,IK)
      DISREFL=HUBDIM(6,IK)
      FWDRAD=FWDDIAM/2.0
      AFTRAD=AFTDIAM/2.0
      HUBDIAM=X(1)*DIAM
      HUBRAD=HUBDIAM/2.0
      FRBORE=FDBORE/2.
      ARBORE=ADBORE/2.
      GO TO 270
   50 CENGRVH=HUBLEN/2.
  270 CONTINUE

C        ****WEIGHT CALCULATION****
      DO 10 I=1,JC
   10 A(I)=CHORD(I)*THICKNS(I)
C        WEIGHT OF THE BLADES
      BSA1=SIMPUN(X,A,JC)
      WEIGHTB=CNSTNT1*DIAM*DEN*ZZ*BSA1
C        WEIGHT OF THE HUB
      IF(HUB.EQ.0.) GO TO 200
      IF(FWDDIAM-AFTDIAM) 201,200,201
  201 WEIGHHT=DEN*PI*HUBLEN/4.*((FWDRAD+AFTRAD)**2+((FWDRAD-AFTRAD)**2/3
     1.0))
      WEIGHBR=DEN*PI*HUBLEN/4.*((FRBORE+ARBORE)**2+((FRBORE-ARBORE)**2/3
     1.0))
      WEIGHTH=WEIGHHT+WEIGHBR
```

```
      CENGRVH=HUBLEN- (((HUBLEN*(FWDRAD**2+2.*FWDRAD*AFTRAD+3.*AFTRAD**2
     1)/(4.*(FWDRAD**2+FWDRAD*AFTRAD+AFTRAD**2)))*WEIGHHT-(HUBLEN*(FRBOR
     2E**2+2.*FRBORE*ARBORE+3.*ARBORE**2)/(4.*(FRBORE**2+FRBORE*ARBORE+A
     3RBORE**2)))*WEIGHBR)/WEIGHTH)
      GO TO 202
  200 WEIGHTH=PI*HUBDIAM**2*HUBLEN*DEN/4.
  202 CONTINUE
C        WEIGHT OF THE PROPELLER
      WEIGHTP=WEIGHTB+WEIGHTH

C        ****CENTER OF GRAVITY CALCULATION****
      DO 20 I=1,JC
   20 DISTHF(I)=CNSTNT2*CAMBER(I)*COS(PITCH(I))+CNSTNT3*CHORD(I)
     1*SIN(PITCH(I))+DISREFL

C        THE EFFECT OF RAKE AND SKEW ARE ADDED TO THE DISTANCE OF THE CE
C        GRAVITY FROM THE HUB FACE FOR EACH SECTION.
      DO 30 I=1,JC
      DISTHF(I)=DISTHF(I)-SKEWR(I)*X(I)/2.*DIAM*TAN(PITCH(I))-TAN(RAKE*
     1PI/180.)*DIAM/2.*(X(11)-X(1))
   30 A(I)=CHORD(I)*THICKNS(I)*DISTHF(I)
      BSA2=SIMPUN(X,A,JC)
      CENGRV3=BSA2/BSA1
      CENGRVB=DISREFL-CENGRV3
C        CENTER OF GRAVITY CONSIDERING RAKE AND SKEW
      CENGRV1=(WEIGHTB*CENGRV3+WEIGHTH*CENGRVH)/WEIGHTP
      CENGRVF=DISREFL-CENGRV1

       IF(JPR.NE.2) GO TO    53
       SWT=4.44822
       UB=WEIGHTB*SWT
       UP=WEIGHTP*SWT
       CFL=CENGRVF/DIAM
       CBL=CENGRVB/DIAM
       BA=HUBLEN/DIAM
       BB=FWDDIAM/DIAM
       BC=AFTDIAM/DIAM
       BD=DISREFL/DIAM
       BE=HUBDIAM/DIAM
       BF=FDBORE/DIAM
       BG=ADBORE/DIAM
C        ****RESULTS OUTPUT****
      IF(HUB.EQ.0.) GO TO 55
       PRINT 107, UB,UP,CFL,CBL
       PRINT 108,  BA,BB,BC,BD,BE,BF,BG
      GO TO 53
   55 CONTINUE
       PRINT 104, UB,UP,CFL,CBL
       PRINT 110,  BE,BA,BD
   53 CONTINUE

C        MINIMUM EXPANDED AREA RATIO CALCULATIONS
      AJS=VS/(RPS*DIAM)
      AJA=WAKE*AJS
      AKT=PI*CTS*AJS**2/8.
      AKQ=CPS*AJS**3/16.
      EARMIN=(2.6+0.6*ZZ)*AKT/(SIGMA7*(AJA**2+(.7*PI)**2))+.15
```

```
      IF(JPR.NE.2) RETURN
      PRINT 105,EARMIN,AJS,AJA,AKT,AKQ,   PC

  104 FORMAT(  //20X,*WEIGHT OF BLADES(N)=*,F15.4//20X,*WEIGHT OF PROP(B
     1LADES+CYLINDRICAL HUB)(N)=*                ,F15.4//20X,*CENTER OF GRA
     2VITY OF PROP REFERENCED FROM MIDCHORD OF ROOT SECTION (- FWD, + AF
     3T)/D=*       ,F9.6//20X,*CENTER OF GRAVITY OF BLADES REFERENCED FROM
     4 MIDCHORD OF ROOT SECTION (- FWD, + AFT)/D=*     ,F9.6)
  105 FORMAT(/20X,*KELLERS MINIMUM EAR=*,E10.4
     1//20X,*SPEED COEFF   V/(ND)     JS=*,E10.4//20X,*ADVANCE COEFF    V(
     21-WTT)/(ND)    JA=*,E10.4//20X,*DESIGN THRUST COEFF     KT=*,E
     310.4//20X,*TORQUE COEFF     KQ=*,E10.4//
     4  20X,*PROPULSIVE EFFICIENCY  ETAD=*,E10.4)
  110 FORMAT(/20X,*HUB DIMENSIONS/D*    11X,*HUB DIAM =*F9.6/47X,  *HUB L
     1ENGTH =*,F9.4/47X,*MIDCHORD OF ROOT SECTION TO AFT END OF HUB =*,F
     29.4)
  100 FORMAT(6F8.4)
  107 FORMAT(  //20X,*WEIGHT OF BLADES(N)=*,F15.4//20X,*WEIGHT OF PROP(B
     1LADES+TAPERED HUB)(N)=*                   ,F15.4//20X,*CENTER OF GRA
     2VITY OF PROP REFERENCED FROM MIDCHORD OF ROOT SECTION (- FWD, + AF
     3T)/D=*       ,F9.6//20X,*CENTER OF GRAVITY OF BLADES REFERENCED FROM
     4 MIDCHORD OF ROOT SECTION (- FWD, + AFT)/D=*     ,F9.6)
  108 FORMAT(/20X,*HUB DIMENSIONS/D*     ,11X,*LENGTH=*,F9.4/47X,*FWD DIA
     1M=*,F9.4/47X,*AFT DIAM=*,F9.4/47X,*MIDCHORD OF ROOT SECTION TO AFT
     2 END OF HUB=*,F9.4/47X,*HUB DIAM AT MIDCHORD OF ROOT SECTION=*,F9.
     34/47X,*FWD DIAM OF BORE=*,F9.4/47X,*AFT DIAM OF BORE=*,F9.4)
      END
```

```
      SUBROUTINE FIELD(ABC,UA,UT,UR,IK,DEX,COM,IPO)
C     *** MAIN ***  FPV-7    FIELD POINT VELOCITIES AUG 28,1969
      DIMENSION A1(792),KB(20,41),S1(792),U1(792),XR(11),XG(11),XTB(11),
     1XSL(11),XST(11),XVX(11),XUA(11),XTZ(11),Z(36),P(36)
      DIMENSION ABC(11,9)
       COMMON /WRT/ JPR
      DIMENSION DEX(11,3,2),COM(12,2)
      DIMENSION UA(11),UT(11),KV(11),UR(11)
      COMMON A(42,42),A3(24,11,3),S(24,11,3),U(24,11,3),XINPUT(11,16),B(
     142,2),SINKN(20,24),XSTAR(11
     1),COSI(42),COEX(5),COSKN(20,24),GB(20,42),GLR(20),GLRZ(20),G(20),G
     2MA(100),GLT(20),GT(20,42),GTL(20),MHUB(17),NLE(20),NTE(20),NUM(41)
     3,PHI(42),REMARK(18),R(20),RVLAM(20,11),RV(11),RVSQ(11),RZLAM(20),R
     3ZRV
     42(20,11),RZRV(20,11),RZ(20),RZSQ(20),SB(20,42),SINI(42)
     5,SL(20),SMA(42),SOLAM(20),STAR(20),ST(20),SPACE(42),T(24,2),WEIGHT
     6(5),X(42),XGL(11),XMAP(11),AY,AM,AA,AB,AC,AD,AE,AF,AG,AH,AI
     7,AL,BUG,BLADD,BLADE,BBL,BB,BOG,BUB,CHOR,COSIKN,COSY,CCA,CCL,C,DEGR
     8EE,DELT,DET,D2,D516,D75,D8,DELM,D,DELTA,DU,DV,DW,EX,E,EXGNU,GMU1,G
     9NU,GLMAX,GLMIN,GMU2,H,IMAX,JT,KT,LINE,MAX,MOUSE,MT,MIN
     1,NT,NX2,NSTOP,NTHICK,NX,NIN,NMAX,NMIN,NLEM,NLL,NTEM,NVV,NCOSE,NOGO
     2,PP,QQ,Q,RH,RBASE,RMAP,SLM,STM,SINIKN,SINY,SSL,TTHICK,TP,V,XL,XP,A
     3NGLE(33),P,Z
      DIMENSICN CN(4,3)
      EQUIVALENCE  (A,KB),(A3,A1),(S1,S),(U1,U),(XR,XINPUT),
     1(XG,XINPUT(12)),(XTB,XINPUT(23)),(XSL,XINPUT(34)),
     2(XST,XINPUT(45)),(XVX,XINPUT(56)),(XUA,XINPUT(67)),
     3(XTZ,XINPUT(78))
      NOGO=10
      MHUB(1)=0
      MHUB(2)=4
      MHUB(3)=12
      MHUB(4)=30
      MHUB(5)=60
        MHUB(6)=120
      MHUB(7)=240
      MHUB(8)=360
      MHUB(9)=720
      MHUB(10)=4320
      DO 51      N=1,NOGO
      J=N+NOGO-1
      M=NOGO-N+1
      ANGLE(J)=FLOAT(MHUB(N))*.17453293E-01
   51 ANGLE(M)=-ANGLE(J)
      NOGO=2*NOGO-1
      IX=0
      NSTOP=DEX(1,1,IK)
      NEX=DEX(3,1,IK)
    1 CONTINUE
  100 FORMAT(I4)
      IF(NSTOP)     2,99,3
   99 RETURN
  109 FORMAT(18A4)
    3 CONTINUE
      NX=11
      KT=ABC(2,9)
      LINE=1
```

```
      MT=12
      NT=12
      NTHICK=23
      AY=0.8
      BU3=6.0
      TTHICK=.1
      DO 87 I=1,11
      DO 87 J=1,8
   87 XINPUT(I,J)=ABC(I,J)
      XINPUT(1,9)=0.0
      XINPUT(2,9)=0.5
      XINPUT(3,9)=1.25
      XINPUT(4,9)=5.0
      XINPUT(5,9)=10.0
      XINPUT(6,9)=15.0
      XINPUT(7,9)=20.0
      XINPUT(8,9)=25.0
      XINPUT(9,9)=30.0
      XINPUT(1,10)=35.0
      XINPUT(2,10)=40.0
      XINPUT(3,10)=45.0
      XINPUT(4,10)=50.0
      XINPUT(5,10)=55.0
      XINPUT(6,10)=60.0
      XINPUT(7,10)=65.0
      XINPUT(8,10)=70.0
      XINPUT(9,10)=75.0
      XINPUT(1,11)=80.0
      XINPUT(2,11)=85.0
      XINPUT(3,11)=90.0
      XINPUT(4,11)=95.0

      XINPUT(5,11)=100.0
      DO 93 I=6,9
   93 XINPUT(I,11)=0.0
      DO 94 I=1,9
   94 XINPUT(I,12)=0.0
      XINPUT(1,13)=0.0
      XINPUT(2,13)=.9120
      XINPUT(3,13)=1.004
      XINPUT(4,13)=1.0611
      XINPUT(5,13)=1.0818
      XINPUT(6,13)=1.0927
      XINPUT(7,13)=1.1004
      XINPUT(8,13)=1.1060
      XINPUT(9,13)=1.1095
      XINPUT(1,14)=1.1120
      XINPUT(2,14)=1.1142
      XINPUT(3,14)=1.1153
      XINPUT(4,14)=1.1139
      XINPUT(5,14)=1.1102
      XINPUT(6,14)=1.1046
      XINPUT(7,14)=1.0970
      XINPUT(8,14)=1.0868
      XINPUT(9,14)=1.0740
      XINPUT(1,15)=1.0579
      XINPUT(2,15)=1.03636
```

```
      XINPUT(3,15)=1.01020
      XINPUT(4,15)=1.143
      XINPUT(5,15)=0.0
      DO 88 I=6,9
   88 XINPUT(I,15)=0.0
      DO 89 I=1,9
   89 XINPUT(I,16)=0.0
      DO 15 I=1,9
      Z(I)=XINPUT(I,9)
      Z(I+9)=XINPUT(I,10)
      Z(I+18)=XINPUT(I,11)
      Z(I+27)=XINPUT(I,12)
      P(I)=XINPUT(I,13)
      P(I+9)=XINPUT(I,14)
      P(I+18)=XINPUT(I,15)
   15 P(I+27)=XINPUT(I,16)
      IF(NT)  52,99,53
   52 NT=-NT
      NHELIX=-1
      GO TO  54
   53 NHELIX=1
   54 RH=XR(1)
      DELT=.17453293E-01*BUB
      IF(XTB(2))    99,32,33
32    BUG=XTB(1)
      DO 34        N=1,NX
34    XTB(N)=BUG/XR(N)
33    IF(XVX(1))    99,35,36
35    DO 37        N=1,NX
37    XVX(N)=1.0
36    IF(XUA(2))    99,38,39
38    BUG=XUA(1)
      DO 40        N=1,NX
40    XUA(N)=(XTB(N)*XR(N)/BUG-XVX(N))/(1.0+XTB(N)**2)
39    IF(XTZ(2))    99,41,42
41    BUG=XTZ(1)
      DO 43        N=1,NX
43    XTZ(N)=BUG*(1.0-XR(N))
42    DO 4         N=1,NX
      XMAP(N)=COMAP(XR(N),RH)
      XGL(N)=XR(N)*XTB(N)
      BUG=XGL(N)*(XST(N)-XSL(N))
      IF(BUG.GT.0.0001)  GO TO 55
      XSTAR(N)=2.0*XSTAR(N-1)-XSTAR(N-2)
      GO TO 4
55    XSTAR(N)=XTZ(N)*DELT*(XGL(N)**2+XR(N)**2)*(XVX(N)+XUA(N))/
     1  (XGL(N)*(XST(N)-XSL(N)))
4     CONTINUE
      NX2=NX-2
      DO 5         I=1,NX2
      B(I,1)=XG(I+1)
      DO 5         J=1,NX2
5     A(I,J)=SIN(FLOAT(J)*XMAP(I+1))
      IF(XG(1))    99,6,7
6     DET=1.0
       CALL  MATINV(A,NX2,B,1,DET,MOUSE)
       GO TO (8 ,99),MOUSE
```

```
5     CONTINUE
      B(NX2+1,1)=0.0
      B(NX,1)=0.0
      GO TO 11
7     XG(1)=0.0
      XG(NX)=8.0
      DO 9       I=1,NX2
      XG(I+1)=0.0
      DO 9       J=1,NX2
9     XG(I+1)=XG(I+1)+A(I,J)*B(J,1)
 11   IF(JPR.NE.3) GO TO    60
300   FORMAT(1H1)
      WRITE(6,300)
      WRITE(6,102) (COM(N,IK),N=1,12),NX,LINE,MT,BUB,KT,AY
      WRITE  (6,104)NT,NTHICK,(XR(N),XTB(N),XGL(N),XSL(N),XST(N),XG(N), B
     1(N,1),XVX(N),XUA(N),XTZ(N),N=1,NX)
      WRITE  (6,103)TTHICK,(Z(N),P(N),N=1,NTHICK)
102   FORMAT(////38X,32H**********  MIT-FPV-7  *********/38X,32HPROPELLE
     1R FIELD POINT VELOCITIES/25X,12A6/11X,21HNUMBER OF INPUT RADII,8X,
     2I2,20X,18HTYPE OF CHORD LOAD,5X,I1/11X,19HLATTICE ARRANGEMENT,32X,
     317H(1=NACA A-SERIES)/13X,26HNO.OF FULL RADIAL SPACES  I2,21X,17H(2
     4=ELLIPTICAL   )/13X,26HANGULAR SPACING -DEGREES- F4.1,19X,17H(3=FL
     5AT PLATE   )/11X,16HNUMBER OF BLADES,12X,I2,21X,16HA-DESIGNATION O
     6F/11X,18HNO.OF FIELD POINTS,33X,17HTYPE 1 CHORD LOAD,6X,F4.2)
104   FORMAT(11X,14HBETWEEN BLADES,13X,I3,21X,25HNO.OF POINTS IN THICKNE
     1SS/11X,34H(NEGATIVE FOR HELICAL COORDINATES),17X,16HFORM INPUT TAB
     2LE,6X,I2///13X,1HR,6X,22HTAN BI  LAMBDA I    SL,7X,2HST,7X,1HG,8X,
     335HC(N)     VA/VS    UA*/VS     TO//(7X,6F9.4,F11.6,F8.3,F8.4,F9.4))
103   FORMAT(///24X,54HVELOCITY DISTRIBUTION OF 2-D THICKNESS FORM WITH
     1T0/L=F6.4//29X,51HPERCENT CHORD  VELOCITY     PERCENT CHORD  VELOC
     2ITY//(33X,F6.2,6X,F5.3,11X,F6.2,6X,F5.3))
 60   CONTINUE
      DO 44       N=1,NTHICK
44    P(N)=(P(N)-1.0)/TTHICK
      MAX=MT+3
      MIN=MT+2
      DELM=(1.0-RH)/FLOAT(MT)
      D8=DELM*0.125
      D2=DELM*0.5
      D516=DELM*0.3125
      D75=DELM*0.75
      RZ(1)=RH+D8
      RZ(MAX)=1.0-D8
      RZ(2)=RH+D2
      RZ(MIN)=1.0-D2
      RZ(3)=RH+DELM
      R(1)=RH+D516
      R(MIN)=1.0-D516
      R(2)=RH+D75
      R(MT+1)=1.0-D75
      RBASE=RH-D2
      DO 12       M=3,MT
      AM=M-1
      RZ(M+1)=RH+AM*DELM
12    R(M)=RBASE+AM*DELM
      DO 13       M=1,MIN
      RMAP=COMAP(R(M),RH)
```

```
      SL(M)=FILLIN(RMAP,XMAP,XSL,NX)
      ST(M)=FILLIN(RMAP,XMAP,XST,NX)
      GLR(M)=FILLIN(R(M),XR,XGL,NX)
      STAR(M)=FILLIN(R(M),XR,XSTAR,NX)
      GLRZ(M)=FILLIN(RZ(M),XR,XGL,NX)
      G(M)=0.0
      DO 13       J=1,NX2
   13 G(M)=G(M)+B(J,1)*SIN(FLOAT(J)*RMAP)
      GLRZ(MAX)=FILLIN(RZ(MAX),XR,XGL,NX)
      DO 17       N=1,41
      DO 17       M=1,20
      GB(M,N)=0.0
      GT(M,N)=0.0
   17 SB(M,N)=0.0
      CALL FAN
      DO 14       N=1,41
      NUM(N)=N
      DO 14       M=1,19
   14 KB(M,N)=100000.0*GB(M,N)
      DO 45       N=1,41
      DO 45       M=1,19
   45 KB(M,N)=100000.0*GT(M,N)
      DO 46       N=1,41
      DO 46       M=1,19
   46 KB(M,N)=100000.0*SB(M,N)
    2 JT=DEX(2,1,IK)
      NEX=NEX-1
      IX=IX+1
      EX=DEX(IX,2,IK)
      DO 105 J=1,JT
  105 RV(J)=DEX(J,3,IK)
      BUG=0.0
      IF(NHELIX)  47,48,48
   47 BUG=-EX/XGL(NX)
   48 BLADD=6.2831853/FLOAT(KT)
      BUB=BLADD/FLOAT(NT)
      BLADE=BUG
      DO 49       N=1,NT
      T(N,1)=-BUG/.17453293E-01
      DO 50       K=1,KT
      COSKN(K,N)=COS(BUG)
      SINKN(K,N)=SIN(BUG)
   50 BUG=BUG+BLADD
      BUG=BLADE-BUB
   49 BLADE=BUG
      DO 18       M=1,MAX
      RZSQ(M)=RZ(M)**2
      RZLAM(M)=RZ(M)*GLRZ(M)
      DO 18       J=1,JT
      RZRV(M,J)=RZ(M)*RV(J)
   18 RZRV2(M,J)=2.0*RZRV(M,J)
      DO 19       J=1,JT
      RVSQ(J)=RV(J)**2
      DO 19       M=1,MAX
   19 RVLAM(M,J)=RV(J)*GLRZ(M)
      BUG=EX/(.17453293E-01*XGL(NX))
      DO 31   N=1,NT
```

```
31    T(N,2)=T(N,1)-BUG
      D8=XGL(NX)/((1.0+XGL(NX)**2)*XUA(NX)+1.0)
      D2=9.8696044*D8/XVX(NX)
      BLADE=FLOAT(KT)
      NSTOP=IABS(NSTOP)
      GO TO (20,21,21,20),NSTOP
20    CALL LTRAIL
      DO 23 J=1,JT
   23 CALL SUMOUT(EX,RV(J),T,S,S,NT,J,REMARK,1,D2,D8,BLADE,CN)
21    GO TO (1,24,25,24),NSTOP
24    CALL VORCES
      DO 26 J=1,JT
   26 CALL SUMOUT(EX,RV(J),T,U,S,NT,J,REMARK,2,D2,D8,BLADE,CN)
      DO 22 J=1,JT
   22 CALL SUMOUT(EX,RV(J),T,A3,S,NT,J,REMARK,3,D2,D8,BLADE,CN)
25    GO TO (1,1,27,27),NSTOP
27    CALL BTRAIL
      DO 28 J=1,JT
   28 CALL SUMOUT(EX,RV(J),T,U,S,NT,J,REMARK,4,D2,D8,BLADE,CN)
      GO TO(1,1,1,29),NSTOP
   29 DO 30 J=1,JT
      CALL SUMOUT(EX,RV(J),T,S,S,NT,J,REMARK,5,D2,D8,BLADE,CN)
      UA(J)=CN(1,1)
      UR(J)=CN(1,2)
   30 UT(J)=CN(1,3)
      IF(NEX) 200,201,200
  200 NSTOP=4
      GO TO 1
  201 NSTOP=0
      GO TO 1
      END
```

```
C      *** FAN ***    FPV-7    FIELD POINT VELOCITIES AUG 20,1969
       SUBROUTINE FAN
       DIMENSICN A1(792),KB(20,41),S1(792),U1(792),XR(11),XG(11),XTB(11),
      1XSL(11),XST(11),XVX(11),XUA(11),XTZ(11),Z(36),P(36)
       COMMON A(42,42),A3(24,11,3),S(24,11,3),U(24,11,3),XINPUT(11,16),B(
      142,2),SINKN(20,24),XSTAR(11
      1),COSI(42),COEX(5),COSKN(20,24),GB(20,42),GLR(20),GLRZ(20),G(20),G
      2MA(100),GLT(20),GT(20,42),GTL(20),MHUB(17),NLE(20),NTE(20),NUM(41)
      3,PHI(42),REMARK(18),R(20),RVLAM(20,11),RV(11),RVSQ(11),RZLAM(20),R
      3ZRV
      42(20,11),RZRV(20,11),RZ(20),RZSQ(20),SB(20,42),SINI(42)
      5,SL(20),SMA(42),SQLAM(20),STAR(20),ST(20),SPACE(42),T(24,2),WEIGHT
      6(5),X(42),XGL(11),XMAP(11),AV,AM,AA,AB,AC,AD,AE,AF,AG,AH,AI
      7,AL,BUG,BLADD,BLADE,BBL,BB,BOG,BUB,CHOR,COSIKN,COSY,CCA,CCL,C,DEGR
      8EE,DELT,DET,D2,D516,D75,D8,DELM,D,DELTA,DU,DV,DW,EX,E,EXGNU,GMU1,G
      9NU,GLMAX,GLMIN,GMU2,H,IMAX,JT,KT,LINE,MAX,MOUSE,MT,MIN
      1,NT,NX2,NSTOP,NTHICK,NX,NIN,NMAX,NMIN,NLEM,NLL,NTEM,NVV,NCOSE,NOGO
      2,PP,QO,Q,RH,RBASE,RMAP,SLM,STM,SINIKN,SINY,SSL,TTHICK,TP,V,XL,XP,A
      3NGLE(33),P,Z
       EQUIVALENCE  (A,KB),(A3,A1),(S1,S),(U1,U),(XR,XINPUT),
      1(XG,XINPUT(12)),(XTB,XINPUT(23)),(XSL,XINPUT(34)),
      2(XST,XINPUT(45)),(XVX,XINPUT(56)),(XUA,XINPUT(67)),
      3(XTZ,XINPUT(78))
       DO 30  N=1,20
       BUG=FLOAT(N)*DELT
       PHI(N+21)=BUG
       MOUSE=21-N
       PHI(MOUSE)=-BUG
       SINI(N+21)=SIN(BUG)
       SINI(MOUSE)=-SINI(N+21)
       COSI(N+21)=COS(BUG)
 30    COSI(MOUSE)=COSI(N+21)
       PHI(21)=0.0
       SINI(21)=0.0
       COSI(21)=1.0
       DO 1  M=1,MIN
       ROOT=SQRT(R(M)**2+GLR(M)**2)
       D=DELT*ROOT
       SLM=SL(M)/ROOT-0.25*DELT
       STM=ST(M)/ROOT+0.25*DELT
       DO 2  N=1,41
       NLEM=N
       IF (PHI(N)-SLM)2,2,4
     2 CONTINUE
     4 DO 5  N=NLEM,41
       NTEM=N-1
       IF (STM-PHI(N))3,3,5
     5 CONTINUE
     3 NVV=NTEM-NLEM+1
       XL=-SL(M)+ROOT*PHI(NLEM)
       CHOR=ST(M)-SL(M)
       IF(NVV-1)    99,33,34
 33    GMA(1)=1.0
       SMA(1)=0.0
       GO TO 35
 34    CALL CHORD
 35    NLE(M)=NLEM
```

```
      NTE(M)=NTEM
      K=1
      DO 1  N=NLEM,NTEM
      GB(M,N)=G(M)*GMA(K)
      SB(M,N)=STAR(M)*SMA(K)
1     K=K+1
      BUG=0.0
      DO 17  N=1,20
      GT(1,N)=-GB(1,N)+BUG
17    BUG=GT(1,N)
      BUG=BUG+G(1)
      GTL(1)=-G(1)
      NTEM=MAX0(21,NTE(1)-1)
      DO 18  N=21,NTEM
      GT(1,N)=-GB(1,N)+BUG
18    BUG=GT(1,N)
      DO 21  M=2,MIN
      BUG=0.0
      DO 20  N=1,20
      GT(M,N)=GB(M-1,N)-GB(M,N)+BUG
20    BUG=GT(M,N)
      GTL(M)=G(M-1)-G(M)
      BUG=BUG-GTL(M)
      NTEM=MAX0(21,NTE(M-1)-1,NTE(M)-1)
      DO 21  N=21,NTEM
      GT(M,N)=GB(M-1,N)-GB(M,N)+BUG
21    BUG=GT(M,N)
      BUG=0.0
      DO 22  N=1,20
      GT(MAX,N)=GB(MIN,N)+BUG
22    BUG=GT(MAX,N)
      BUG=BUG-G(MIN)
      GTL(MAX)=G(MIN)
      NTEM=MAX0(21,NTE(MIN)-1)
      DO 23  N=21,NTEM
      GT(MAX,N)=GB(MIN,N)+BUG
23    BUG=GT(MAX,N)
      RETURN
   99 STOP
      END
```

```
C      *** CHORD ***    FPV-7  FIELD POINT VELOCITIES AUG 28,1969
       SUBROUTINE CHORD
       DIMENSION A1(792),KB(20,41),S1(792),U1(792),XR(11),XG(11),XTB(11),
      1XSL(11),XST(11),XVX(11),XUA(11),XTZ(11),Z(36),P(36)
       COMMON A(42,42),A3(24,11,3),S(24,11,3),U(24,11,3),XINPUT(11,16),B(
      142,2),SINKN(20,24),XSTAR(11
      1),COSI(42),COEX(5),COSKN(20,24),GB(20,42),GLR(20),GLRZ(20),G(20),G
      2MA(100),GLT(20),GT(20,42),GTL(20),MHUB(17),NLE(20),NTE(20),NUM(41)
      3,PHI(42),REMARK(18),R(20),RVLAM(20,11),RV(11),RVSQ(11),RZLAM(20),R
      3ZRV
      42(20,11),RZRV(20,11),RZ(20),RZSQ(20),SB(20,42),SINI(42)
      5,SL(20),SMA(42),SQLAM(20),STAR(20),ST(20),SPACE(42),T(24,2),WEIGHT
      6(5),X(42),XGL(11),XMAP(11),AY,AM,AA,AB,AC,AD,AE,AF,AG,AH,AI
      7,AL,BUG,BLADD,BLADE,BBL,BB,BOG,BUB,CHOR,COSIKN,COSY,CCA,CCL,C,DEGR
      8EE,DELT,DET,D2,D516,D75,D8,DELM,D,DELTA,DU,DV,DW,EX,E,EXGNU,GMU1,G
      9NU,GLMAX,GLMIN,GMU2,H,IMAX,JT,KT,LINE,MAX,MOUSE,MT,MIN
      1,NT,NX2,NSTOP,NTHICK,NX,NIN,NMAX,NMIN,NLEM,NLL,NTEM,NVV,NCOSE,NOGO
      2,PP,QQ,Q,RH,RBASE,RMAP,SLM,STM,SINIKN,SINY,SSL,TTHICK,TP,V,XL,XP,A
      3NGLE(33),P,Z
       EQUIVALENCE  (A,KB),(A3,A1),(S1,S),(U1,U),(XR,XINPUT),
      1(XG,XINPUT(12)),(XTB,XINPUT(23)),(XSL,XINPUT(34)),
      2(XST,XINPUT(45)),(XVX,XINPUT(56)),(XUA,XINPUT(67)),
      3(XTZ,XINPUT(78))
       B(1,1)=1.0
       B(1,2)=0.0
       DO 1        N=1,NVV
       A(1,N)=1.0
       DO 1        M=2,NVV
 1     A(M,N)=1.0/(FLOAT(N-M)+0.5)
       NMIN=NVV-1
       BUB=100.0/CHOR
       DO 2        M=1,NMIN
       X(M)=XL+(FLOAT(M)-0.5)*D
       AG=X(M)*BUB
 2     B(M+1,2)=FILLIN(AG,Z,P,NTHICK)
       GO TO  (3,5,6),LINE
 3     IF(AY-0.99 )      4,4,17
C      CASE 1      CONSTANT LOAD
 17    DO 7        M=2,NVV
 7     B(M,1)=D*(ALOG(1.0-X(M-1)/CHOR)-ALOG(X(M-1)/CHOR))/CHOR
       GO TO 11
C      CASE 2       A SERIES MEAN LINE
 4     E=1.0-AY
       DO 8        M=2,NVV
       V=1.0-X(M-1)/CHOR
       Q=AY-X(M-1)/CHOR
       IF(ABS(Q)-0.0001) 14,14,15
 14    QQ=0.0
       GO TO 16
 15    QQ=Q*ALOG(ABS(Q))
 16    PP=V*ALOG(V)
 8     B(M,1)=2.0*D*((PP-QQ)/E-ALOG(X(M-1)/CHOR)-1.0)/((AY+1.0)*CHOR)
       GO TO 11
C      CASE 3       ELLIPTICAL LOADING
 5     DO 9        M=2,NVV
 9     B(M,1)=4.0*D*(1.0-2.0*X(M-1)/CHOR)/CHOR
       GO TO 11
```

```
C      *** LTRAIL ***  FPV-7  FIELD POINT VELOCITIES AUG 20,1969
       SUBROUTINE LTRAIL
       DIMENSION A1(792),KB(20,41),S1(792),U1(792),XR(11) XG(11),XTB(11),
      1XSL(11),XST(11),XVX(11),XUA(11),XTZ(11),Z(36),P(36)
       COMMON A(42,42),A3(24,11,3),S(24,11,3),U(24,11,3),XINPUT(11,16),B(
      142,2),SINKN(20,24),XSTAR(11
      1),COSI(42),COEX(5),COSKN(20,24),GB(20,42),GLR(20),GLRZ(20),G(20),G
      2MA(100),GLT(20),GT(20,42),GTL(20),KHUB(17),NLE(20),NTE(20),NUM(41)
      3,PHI(42),REMARK(18),R(20),RVLAM(20,11),RV(11),RVSQ(11),RZLAM(20),R
      3ZRV
      42(20,11),RZRV(20,11),RZ(20),RZSQ(20),SB(20,42),SINI(42)
      5,SL(20),SMA(42),SQLAM(20),STAR(20),ST(20),SPACE(42),T(24,2),WEIGHT
      6(5),X(42),XGL(11),XMAP(11),AY,AM,AA,AB,AC,AD,AE,AF,AG,AH,AI
      7,AL,BUG,BLADD,BLADE,BBL,BB,BOG,BU3,CHOP,COSIKN,COSY,CCA,CCL,C,DEGR
      8EE,DELT,DFT,D2,D516,D75,D8,DELM,D,DELTA,DU,DV,DW,EX,E,EXGNU,GMU1,G
      9NU,GLMAX,GLMIN,GMU2,H,IMAX,JT,KT,LINE,MAX,MOUSE,MT,MIN
      1,NT,NX2,NSTOP,NTHICK,NX,NIN,NMAX,NMIN,NLEM,NLL,NTEM,NVV,NCOSE,NOGO
      2,PP,QQ,Q,RH,RBASE,RMAP,SLM,STM,SINIKN,SINY,SSL,TTHICK,TP,V,XL,XP,A
      3NGLE(33),P,Z
       EQUIVALENCE  (A,KB),(A3,A1),(S1,S),(U1,U),(XR,XINPUT),
      1(XG,XINPUT(12)),(XTB,XINPUT(23)),(XSL,XINPUT(34)),
      2(XST,XINPUT(45)),(XVX,XINPUT(56)),(XUA,XINPUT(67)),
      3(XTZ,XINPUT(78))
       DO 5 N=1,792
 5     S1(N)=0.0
       BUG=40.0
       DO 1       J=1,JT
       DO 1       M=1,MAX
       BOG=ABS(RV(J)-RZ(M))
       IF(BOG-BUG)  2,1,1
 2     BUG=BOG
       TP=EX/GLRZ(M)
 1     CONTINUE
       IF(TP-ANGLE(1))  3,3,4
 4     DO 7       M=1,NOGO
       NLOW=M
       IF(ANGLE(M)+TP)  7,7,8
 7     CONTINUE
 8     IF(NLOW-1)  10,10,11
 10    GMA(1)=TP+ANGLE(1)
       GO TO 12
 11    GMA(1)=0.0
 12    N=2
       DO 9       M=NLOW,NOGO
       GMA(N)=TP+ANGLE(M)
 9     N=N+1
       NCODE=NOGO-NLOW+1
       DO 6       I=1,NCODE
       DELTA=GMA(I+1)-GMA(I)
       COEX(1)=.046910*DELTA
       COEX(2)=.230765*DELTA
       COEX(3)=.5*DELTA
       COEX(4)=.769235*DELTA
       COEX(5)=.953090*DELTA
       WEIGHT(1)=.059232*DELTA
       WEIGHT(5)=WEIGHT(1)
       WEIGHT(2)=.119657*DELTA
```

```
      WEIGHT(4)=WEIGHT(2)
      WEIGHT(3)=.142222*DELTA
      DO 6      L=1,5
      GNU=GMA(I)+COEX(L)
      COSY=COS(GNU)
      SINY=SIN(GNU)
      DO 6      K=1,KT
      DO 6      N=1,NT
      COSIKN=COSY*COSKN(K,N)-SINY*SINKN(K,N)
      SINIKN=SINY*COSKN(K,N)+COSY*SINKN(K,N)
      DO 6      J=1,JT
      DO 6      M=1,MAX
      BOG=SQRT(((EX-GLPZ(M)*GNU)**2+RVSQ(J)+RZSQ(M)-RZRV2(M,J)* COSIKN)*
     1*3)
      BOG=WEIGHT(L)*GTL(M)/BOG
      EXGNU=(EX-GLRZ(M)*GNU)*RZ(M)
      S(N,J,1)=S(N,J,1)+(RZSQ(M)-RZRV(M,J)*COSIKN)*BOG
      S(N,J,2)=S(N,J,2)+(RZLAM(M)*SINIKN+EXGNU*COSIKN)*BOG
      S(N,J,3)=S(N,J,3)+(RVLAM(M,J)-RZLAM(M)*COSIKN+EXGNU*SINIKN)*BOG
6     CONTINUE
3     RETURN
      END
```

```
C     *** VORCES ***  FPV-7  FIELD POINT VELOCITIES  AUG 20,1969
      SUBROUTINE VORCES
      DIMENSION A1(792),KB(20,41),S1(792),U1(792),XR(11),XG(11),XTB(11),
     1XSL(11),XST(11),XVX(11),XUA(11),XTZ(11),Z(36),P(36)
      COMMON A(42,42),A3(24,11,3),S(24,11,3),U(24,11,3),XINPUT(11,16),B(
     142,2),SINKN(20,24),XSTAR(11
     1),COSI(42),COEX(5),COSKN(20,24),GB(20,42),GLR(20),GLRZ(20),G(20),G
     2MA(100),GLT(20),GT(20,42),GTL(20),MHUB(17),NLE(20),NTE(20),NUM(41)
     3,PHI(42),REMARK(18),R(20),RVLAM(20,11),RV(11),RVSQ(11),RZLAM(20),R
     3ZRV
     42(20,11),RZRV(20,11),RZ(20),RZSQ(20),SB(20,42),SINI(42)
     5,SL(20),SMA(42),SQLAM(20),STAR(20),ST(20),SPACE(42),T(24,2),WEIGHT
     6(5),X(42),XGL(11),XMAP(11),AY,AM,AA,AB,AC,AD,AE,AF,AG,AH,AI
     7,AL,BUG,BLADD,BLADE,BBL,BB,BOG,BUB,CHOR,COSIKN,COSY,CCA,CCL,C,DEGR
     8EE,DELT,DET,D2,D516,D75,D8,DELM,D,DELTA,DU,DV,DW,EX,E,EXGHU,GMU1,G
     9NU,GLMAX,GLMIN,GMU2,H,IMAX,JT,KT,LINE,MAX,MOUSE,MT,MIN
     1,NT,NX2,NSTOP,NTHICK,NX,NIN,NMAX,NMIN,NLEM,NLL,NTEM,NVV,NCOSE,NOGO
     2,PP,OO,Q,RH,RBASE,RMAP,SLM,STM,SINIKN,SINY,SSL,TTHICK,TF,V,XL,XP,A
     3NGLE(33),P,Z
      EQUIVALENCE  (A,KB),(A3,A1),(S1,S),(U1,U),(XR,XINPUT),
     1(XG,XINPUT(12)),(XTB,XINPUT(23)),(XSL,XINPUT(34)),
     2(XST,XINPUT(45)),(XVX,XINPUT(56)),(XUA,XINPUT(67)),
     3(XTZ,XINPUT(78))
      DO 3 N=1,792
      U1(N)=0.0
3     A1(N)=0.0
      DO 5  I=1,41
      DO 1  K=1,KT
      DO 1  N=1,NT
      COSIKN=COSI(I)*COSKN(K,N)-SINI(I)*SINKN(K,N)
      SINIKN=SINI(I)*COSKN(K,N)+COSI(I)*SINKN(K,N)
      DO 1  J=1,JT
      BB=-2.0*RV(J)*COSIKN
      DO 1  MC=1,MIN
      IF(GB(MC,I).EQ.0.0) GO TO 1
      AA=EX-GLR(MC)*PHI(I)
      AB=AA**2+RVSQ(J)
      AC=4.0*(AA**2+RVSQ(J)*SINIKN**2)
      MD=MC+1
      BUG=-1.0
      AG=0.0
      AH=0.0
      AI=0.0
      DO 8  M=MC,MD
      IF(ABS(AC)-0.00001) 4,4,6
4     AE=0.5*BB+RZ(M)
      AD=-0.25/AE**2
      AF=-0.5/AE+0.125*BB/AF**2
      GO TO 7
6     AE=AC*SQRT(RZSQ(M)+RZ(M)*BB+AB)
      AD=(2.0*RZ(M)+BB)/AE
      AF=-(BB*RZ(M)+2.0*AB)/AE
7     AG=AG+BUG*AD*GB(MC,I)
      AH=AH+BUG*AD*SB(MC,I)
      AI=AI+BUG*AF*SB(MC,I)
8     BUG=-BUG
      U(N,J,1)=U(N,J,1)-RV(J)*SINIKN*AG
```

```
      U(N,J,2)=U(N,J,2)+AA*SINIKN*AG
      U(N,J,3)=U(N,J,3)-AA*COSIKN*AG
      A3(N,J,1)=A3(N,J,1)+AA*AH
      A3(N,J,2)=A3(N,J,2)+(RV(J)*AH-COSIKN*AI)
      A3(N,J,3)=A3(N,J,3)-SINIKN*AI
1     CONTINUE
5     CONTINUE
      RETURN
      END
```

```
C     *** BTRAIL ***  FPV-7  FIELD POINT VELOCITIES AUG 20,1969
      SUBROUTINE BTRAIL
      DIMENSION A1(792),KB(20,41),S1(792),U1(792),XR(11),XG(11),XTB(11),
     1XSL(11),XST(11),XVX(11),XUA(11),XTZ(11),Z(36),P(36)
      COMMON A(42,42),A3(24,11,3),S(24,11,3),U(24,11,3),XINPUT(11,16),B(
     142,2),SINKN(20,24),XSTAR(11
     1),COSI(42),COEX(5),COSKN(20,24),GB(20,42),GLR(20),GLRZ(20),G(20),G
     2MA(100),GLT(20),GT(20,42),GTL(20),MHUB(17),NLE(20),NTE(20),NUM(41)
     3,PHI(42),REMARK(18),R(20),RVLAM(20,11),RV(11),RVSQ(11),RZLAM(20),R
     3ZRV
     42(20,11),RZRV(20,11),RZ(20),RZSQ(20),SB(20,42),SINI(42)
     5,SL(20),SMA(42),SQLAM(20),STAR(20),ST(20),SPACE(42),T(24,2),WEIGHT
     6(5),X(42),XGL(11),XMAP(11),AY,AM,AA,AB,AC,AD,AE,AF,AG,AH,AI
     7,AL,BUG,BLADD,BLADE,BBL,BB,BOG,BUB,CHOR,COSIKN,COSY,CCA,CCL,C,DEGR
     8EE,DELT,DET,D2,D516,D75,D8,DELM,D,DELTA,DU,DV,DW,EX,E,EXGNU,GMU1,G
     9NU,GLMAX,GLMIN,GMU2,H,IMAX,JT,KT,LINE,MAX,MOUSE,MT,MIN
     1,NT,NX2,NSTOP,NTHICK,NX,NIN,NMAX,NMIN,NLEM,NLL,NTEM,NVV,NCOSE,NOGO
     2,PP,QQ,Q,RH,RBASE,RMAP,SLM,STM,SINIKN,SINY,SSL,TTHICK,TP,V,XL,XP,A
     3NGLE(33),P,Z
      EQUIVALENCE  (A,KB),(A3,A1),(S1,S),(U1,U),(XR,XINPUT),
     1(XG,XINPUT(12)),(XTB,XINPUT(23)),(XSL,XINPUT(34)),
     2(XST,XINPUT(45)),(XVX,XINPUT(56)),(XUA,XINPUT(67)),
     3(XTZ,XINPUT(78))
      DO 3 N=1,792
    3 U1(N)=0.0
      DO 1       L=1,40
      GMU1=PHI(L)
      DELTA=PHI(L+1)-GMU1
      COEX(1)=0.211325*DELTA
      COEX(2)=0.788675*DELTA
      WEIGHT(1)=0.25*DELTA
      WEIGHT(2)=WEIGHT(1)
      DO 4       I=1,2
      GNU=GMU1+COEX(I)
      COSY=COS(GNU)
      SINY=SIN(GNU)
      DO 4  K=1,KT
      DO 4  N=1,NT
      COSIKN=COSY*COSKN(K,N)-SINY*SINKN(K,N)
      SINIKN=SINY*COSKN(K,N)+COSY*SINKN(K,N)
      DO 4  J=1,JT
      DO 4   M=1,MAX
      IF(GT(M,L).EQ.0.0)  GO TO 4
      BUG=SQRT(((EX-GLRZ  (M)*GNU)**2+RVSQ(J)+RZSQ(M)-RZRV2(M,J)* COSIKN)
     1**3)
      BUG=WEIGHT(I)*GT(M,L)/BUG
      EXGNU=(EX-GLRZ   (M)*GNU)*RZ(M)
      U(N,J,1)=U(N,J,1)+(RZSQ(M)-RZRV(M,J)*COSIKN)*BUG
      U(N,J,2)=U(N,J,2)+(RZLAM(M)*SINIKN+EXGNU*COSIKN)*BUG
      U(N,J,3)=U(N,J,3)+(RVLAM(M,J)-RZLAM(M)*COSIKN+EXGNU*SINIKN)*BUG
    4 CONTINUE
    1 CONTINUE
      RETURN
      END
```

```
C      *** SUMOUT ***  FPV-7  FIELD POINT VELOCITIES AUG 28,1969
       SUBROUTINE SUMOUT(X,R,T,U,S,NT,J,REMARK,KODE,A,B,C,CN)
       DIMENSION T(24,2),U(24,11,3),S(24,11,3),REMARK(18),SN(4,3)
       DIMENSION CN(4,3)
       GO TO (1,2,3,4,5),KODF
     1 GO TO 20
     2 GO TO 20
     3 GO TO 20
     4 GO TO 20
     5 CONTINUE
    20 DO 12 I=1,3
       L=J*I-1
 12    CALL HARMAN(U(1,J,I),T,CN(1,I),SN(1,I),NT,L)
       SP=A*(B*SN(1,1)+R*SN(1,3))
       CP=A*(B*CN(2,1)+R*CN(2,3))
       PM=SQRT(SP**2+CP**2)
       IF(ABS(SP)-0.00001) 13,13,14
 13    PT=90.0*(1.0-SIGN(1.0,CP))/C
       GO TO 15
 14    IF(ABS(CP)-0.00001) 16,16,17
 16    PT=90.0*(2.0-SIGN(1.0,SP))/C
       GO TO 15
 17    PT=(90.0-ATAN(CP/SP)/.17453293E-01)/C
       IF(SP)  18,18,15
 18    PT=PT+180.0/C
    15 CONTINUE
       GO TO (9,8,8,8,9),KODE
 8     DO 7  N=1,NT
       DO 7  K=1,3
       S(N,J,K)=S(N,J,K)+U(N,J,K)
 7     CONTINUE
 9     RETURN
       END


C      *** COMAP ***   FPV-7  FIELD POINT VELOCITIES AUG 20,1969
       FUNCTION COMAP(TEMP,RH)
       IF(TEMP-.999)  1,1,2
 2     COMAP=3.1415926
       GO TO 19
 1     CN=(1.0+RH-2.0*TEMP)/(1.0-RH)
       IF(ABS(CN)-.00001) 17,17,18
    17 COMAP=1.5707963

       GO TO 19
    18 CTN=SQRT(1.0-CN**2)/CN
       COMAP=ATAN(CTN)
       IF(CTN) 20,19,19
 20    COMAP=COMAP+3.1415926
    19 RETURN
C      END OF  *** COMAP ***
       END
```

```
C      *** FILLIN ***  FPV-7  FIELD POINT VELOCITIES AUG 20,1969
C      FINDS Y(X) FROM TABLE OF
C      AB(N) AND OR(N) CONTAINING NO POINTS.
       FUNCTION FILLIN(X,AB,Q000FL,NO)
       DIMENSION AB(3),Q000FL(3)
C      DIMENSION AB(3),OR(3)
       ANTRA(Q001FL,Q002FL,Q003FL,Q004FL,Q005FL,Q006FL,Q007FL)=Q005FL*(Q0
      104FL-Q002FL)*(Q004FL-Q003FL)/((Q001FL-Q002FL)*(Q001FL-Q003FL))+ Q0
      206FL*(Q004FL-Q001FL)*(Q004FL-Q003FL)/((Q002FL-Q001FL)*(Q002FL-Q003
      3FL))+Q007FL*(Q004FL-Q001FL)*(Q004FL-Q002FL)/((Q003FL-Q001FL)* (Q00
      43FL-Q002FL))
       IF(X-AB(1))  1,3,2
  3    Y=Q000FL(1)
       GO TO 99
  1    Y=ANTRA(AB(1),AB(2),AB(3),X,Q000FL(1),Q000FL(2),Q000FL(3))
       GO TO 99
  2    IF(X-AB(2))1,6,5
  6    Y=Q000FL(2)
       GO TO 99
  5    DO 7  I=3,NO
       M=I
       IF(X-AB(I))8,9,7
  9    Y=Q000FL(I)
       GO TO 99
  7    CONTINUE
 8     Y=ANTRA(AB(M-2),AB(M-1),AB(M),X,Q000FL(M-2),Q000FL(M-1),Q000FL(M))
 99    FILLIN=Y
       RETURN
       END
```

```
C      *** HARMAN ***  FPV-7  FIELD POINT VELOCITIES AUG 20,1969
       SUBROUTINE HARMAN(X,T,A,B,NT,JUMP)
       DIMENSION C(24,3),S(24,3),T(24),A(4),B(4),X(24)
       IF(JUMP)  2,1,2
 1     D=NT
       DO 3  N=1,NT
       ANGL=FLOAT(N-1)*360.0/D
       DO 3  K=1,3
       E=FLOAT(K)*ANGL*.17453293E-01
       C(N,K)=2.0*COS(E)/D
 3     S(N,K)=2.0*SIN(E)/D
 2     DO 4  K=1,4
       A(K)=0.0
 4     B(K)=0.0
       DO 5  N=1,NT
       A(1)=A(1)+X(N)
       DO 5  K=1,3
       A(K+1)=A(K+1)+X(N)*C(N,K)
 5     B(K)=B(K)+X(N)*S(N,K)
       A(1)=A(1)/D
       RETURN
       END
```

```
C      MATRIX INVERSION WITH ACCOMPANYING SOLUTION OF LINEAR EQUATIONS
C      NOVEMBER 1692    S GOOD  DAVID TAYLOR MODEL BASIN    AM MAT1
C
       SUBROUTINE MATINV(A,N1,B,M1,DETERM,ID)
C
C      GENERAL FORM OF DIMENSION STATEMENT
C      DIMENSION    A(  ,  ),B(  ,  ),INDEX(  ,3)
C
       DIMENSION A(42,42),B(42,2),INDEX(42,3)
       EQUIVALENCE (IROW,JROW), (ICOLUM,JCOLUM), (AMAX, T, SWAP)
C
C      INITIALIZATION
C
       M=M1
       N=N1
    10 DETERM=1.0
    15 DO 20  J=1,N
    20 INDEX(J,3) = 0
    30 DO 550 I=1,N
C
C      SEARCH FOR PIVOT ELEMENT
C
    40 AMAX=0.0
    45 DO 105 J=1,N
       IF(INDEX(J,3)-1) 60, 105, 60
    60 DO 100 K=1,N
       IF(INDEX(K,3)-1) 80, 100, 715
    80 IF (      AMAX -ABS (A(J,K))) 85, 100, 100
    85 IROW=J
    90 ICOLUM=K
          AMAX = ABS (A(J,K))
   100 CONTINUE
   105 CONTINUE
       INDEX(ICOLUM,3)=INDEX(ICOLUM,3)+1
   260 INDEX(I,1)=IROW
   270 INDEX(I,2)=ICOLUM
C
C      INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL
C
   130 IF (IROW-ICOLUM) 140, 310, 140
   140 DETERM=-DETERM
   150 DO 200 L=1,N
   160 SWAP=A(IROW,L)
   170 A(IROW,L)=A(ICOLUM,L)
   200 A(ICOLUM,L)=SWAP
       IF(M) 310, 310, 210
   210 DO 250 L=1, M
   220 SWAP=B(IROW,L)
   230 B(IROW,L)=B(ICOLUM,L)
   250 B(ICOLUM,L)=SWAP
C
C      DIVIDE PIVOT ROW BY PIVOT ELEMENT
C
   310 PIVOT    =A(ICOLUM,ICOLUM)
       DETERM=DETERM*PIVOT
   330 A(ICOLUM,ICOLUM)=1.0
   340 DO 350 L=1,N
```

```
  350 A(ICOLUM,L)=A(ICOLUM,L)/PIVOT
  355 IF(M) 380, 380, 360
  360 DO 370 L=1,M
  370 B(ICOLUM,L)=B(ICOLUM,L)/PIVOT
C
C     REDUCE NON-PIVOT ROWS
C
  380 DO 550 L1=1,N
  390 IF(L1-ICOLUM) 400, 550, 400
  400 T=A(L1,ICOLUM)
  420 A(L1,ICOLUM)=0.0
  430 DO 450 L=1,N
  450 A(L1,L)=A(L1,L)-A(ICOLUM,L)*T
  455 IF(M) 550, 550, 460
  460 DO 500 L=1,M
  500 B(L1,L)=B(L1,L)-B(ICOLUM,L)*T
  550 CONTINUE
C
C     INTERCHANGE COLUMNS
C
  600 DO 710 I=1,N
  610 L=N+1-I
  620 IF (INDEX(L,1)-INDEX(L,2)) 630, 710, 630
  630 JROW=INDEX(L,1)
  640 JCOLUM=INDEX(L,2)
  650 DO 705 K=1,N
  660 SWAP=A(K,JROW)
  670 A(K,JROW)=A(K,JCOLUM)
  700 A(K,JCOLUM)=SWAP
  705 CONTINUE
  710 CONTINUE
      DO 730 K = 1,N
      IF(INDEX(K,3) -1) 715,720,715
  720 CONTINUE
  730 CONTINUE
      ID =1
  740 RETURN
  715 ID =2
      GO TO 740
      END
```

```
      SUBROUTINE OLD(BZ,IPO)
      DIMENSION AZZ(38,38)
      DIMENSION BZ(111)
      DIMENSION CZ(108),TL(12),B(99),AP(9,3),AQ(9,9),AU(9,9),AW(9,9),AX(
     19,9),AY(9,9),QA(9,9),FT(9),CG(9,1)
      DIMENSION EA(9,8),EB(9,8),EC(9,8),ED(9,8),PA(8),PE(3,3),PG(3,3),PN
     1(3,1),PI(3,1),PF(3),XZ(9,9),WA(9,9),XA(9,9)
      DIMENSION FLD(9),ALD(9),FDCT(9),ADCT(9),FDCP(9),ADCP(9),FDPT(9),AD
     1PT(9),FDMT(36),ADMT(36),FDMQ(36),ADMQ(36),FMTB(9),AMTB(9),FMQB(9),
     2AMQB(9),FMXO(9),AMXO(9),FMYO(9),AMYO(9)
       COMMON /WRT/ JPR
      DIMENSION INDEX(3,3)
      COMMON  CZ     , TL     , B      , AP     , AQ     , AU
      COMMON  AW     , AX     , AY     , QA     , FT     , CG
      COMMON  BO     , BY     , KO     , M3     , CMP ,WA,XA
      DO 30 I=1,12
   30 TL(I)=BZ(I+99)
      KO=1
    1 KOUNT=0
      KT=0
      CMP = 0.0
      CA = 0.0
      DO 5   I=1,9
      B(I+80)=BZ(I+81)
    5 B(I+90)=BZ(I+90)
      GO TO 8
    6 DO 7     I=1,9
      B(I+80)=BZ(15)
    7 B(I+90)=BZ(15)
    8 DO 9   I=1,14
    9 B(I)=BZ(I)
      DO 10  I=1,45
   10 B(I+14)=BZ(I+18)
      B(60)=BZ(15)
      DO 11  I=1,9
      B(I+60)=BZ(I+63)
   11 B(I+70)=BZ(I+72)
      OOOOFL=B(10)
       IF(JPR.NE.2) GO TO    100
      WRITE (6,12)
   12 FORMAT(1H1,44X,32HCONTRA-ROTATING PROPELLER DESIGN//)
      WRITE (6,13)KO
   13 FORMAT (110X,5HPAGE I2)
      WRITE (6,14)
   14 FORMAT(55X,10HINPUT DATA///)
      WRITE (6, 15)(BZ(I),I=1,81)
   15 FORMAT (6X,9F12.4)
      IF (BZ(15))17,16,17
   16 WRITE (6, 15)(BZ(I),I=82,99)
  100  KO=KO+1
   17 ECC=B(10)
      B(12)=.95
      B(13)=1.0
      B(14)=1.05
      PM=B(12)
      KK=0
      BI=3.0
```

```
      BJ=0.0
      BJ1=0.0
      BJ2=0.0
      J1=0
      RSL=B(7)/(3.1415927*B(4)*B(2))
      NZ1=B(10)
      NZ2=B(11)
      DO 300 KI=1,2
      IF(KI-2)201,202,202
201   KJ=3
      GO TO 203
202   KJ=1
203   CONTINUE
        DO 208 KC=1,KJ
      ECC=NZ1
      B(10)=NZ1
      CALL SUB1
   19 DO  20 MO=1,9
        WA(MO,1)=AW(MO,1)
      XA(MO,1)=AX(MO,1)
   20 QA(MO,1)=CG(MO,1)
   21 K2=MB
      GO TO (25,22),K2
   22 N=9
      JP=9
   23 FORMAT(I1)
      K1=JP-N
      IF(K1)1,24,1
   24 GO TO 22
   25 DO 26J=1,9
      KK=4
      EA(J,KK)=AU(J,1)
      EB(J,KK)=AW(J,1)
      EC(J,KK)=AX(J,1)
   26 ED(J,KK)=AY(J,1)
      B(10)=NZ2
      CALL SUB1
      KK=5
      DO 226 J=1,9
      EA(J,KK)=AU(J,1)
      EB(J,KK)=AW(J,1)
      EC(J,KK)=AX(J,1)
226   ED(J,KK)=AY(J,1)
   57 CALL SUB2(ECC,EB,EC,ED,HR,IPO)
      BZ(16)=HR
      PAT=PA(4)+(1.0-FT(9))**2*PA(8)
      DO 58 I=1,9
      IF(I-1) 400,400,401
401   IF(I-9) 402,400,402
400   FLD(I)=.0
      ALD(I)=.0
      GO TO 403
402   CONTINUE
      FLD(I)=CZ(I+9)/B(I+60)
      FLD(I)=B(I+80)/FLD(I)
      ALD(I)=CZ(I+63)/B(I+70)
      ALD(I)=B(I+90)/ALD(I)
```

```
483   CONTINUE
      FDCT(I)=(1.0-FLD(I)*CZ(I))*CZ(I+18)
      ADCT(I)=(1.0-ALD(I)*CZ(I+54))*CZ(I+72)
      FDCP(I)=(1.0+FLD(I)/CZ(I))*CZ(I+27)
      ADCP(I)=(1.0+ALD(I)/CZ(I+54))*CZ(I+81)
      FDPT(I)=B(I+23)*FDCT(I)
   58 ADPT(I)=B(I+32)*ADCT(I)
      FCT=SIMPUN(B(15),FDCT,9)
      ACT=SIMPUN(CZ(46),ADCT,9)
      FCP=SIMPUN(B(15),FDCP,9)
      ACP=SIMPUN(CZ(46),ADCP,9)
      FCPT=SIMPUN(B(15),FDPT,9)
      ACPT=SIMPUN(CZ(46),ADPT,9)
      FFE=FCPT/FCP
      AFE=ACPT/ACP
      FCOC=FCT/FCP
      ACOC=ACT/ACP
      TFCT=FCT+(1.0-FT(9))**2*ACT
      J1=J1+1
      K=J1+12
      B(12)=B(K)
      BY=TFCT
200   PA(KC)=BY
      IF(KI-2)204,67,67
204   CONTINUE
      DO 31J=1,3
      PE(J,1)=1.0
   31 PG(J,1)=1.0
      DO 32J=1,3
      PN(J,1)=PA(J)**2
      PE(J,3)=PN(J,1)
      PG(J,3)=PE(J,3)
      PE(J,2)=PA(J)
   32 PG(J,2)=PE(J,2)
      PI(1,1)=FM
      PI(2,1)=B(13)
      PI(3,1)=B(14)
      CALL MATINS(PE,3,3,PI,1,1,DETERM,ID,INDEX)
      IF(ID-1)33,35,33
   33 PRINT 34
      GO TO 82
   34 FORMAT(18H CTS1* IS SINGULAR)
   35 PK=BQ
      PL=PK**2
      PR=PI(1,1)+PK*PI(2,1)+PL*PI(3,1)
      IF(CA)37,36,37
   36 A4=PR
      CA=1.0
   37 B(12)=PR
   60 CMP=1.0
      DO 61  I=1,9
      B(I+23)=BZ(I+27)
   61 B(I+60)=BZ(I+63)
   62 DO 63  I=1,9
   63 B(I+50)=A4*B(I+50)
   64 CMP=1.0
      B(12)=1.
```

```
300   CONTINUE
   67 TFCP =FCP+(1.0-FT(9))**2*ACP
      TCTP = FCPT + (1.0-FT(9))**2*ACPT
      TFFE = TCTP/TFCP
      TCOC = TFCT/TFCP
      FNMT=B(8)*B(2)**3*3.14159265*B(7)**2/(16.0*B(10))
      ANMT=FNMT*B(10)/B(11)
      FNMQ=(B(8)*B(2)**2*B(7)**3)/(16.0*B(4)*B(10))
      ANMQ=FNMQ*B(10)/B(11)
      M=0
      DO 68 J=1,4
      DO 68 I=1,9
      M=M+1
      K=J*2
      FDMT(M)=(B(I+14)-B(K+13))*FDCT(I)
      ADMT(M)=(CZ(I+45)-CZ(K+44))*ADCT(I)
      FDMQ(M)=(B(I+14)-B(K+13))/B(I+14)*FDCP(I)
   68 ADMQ(M)=(CZ(I+45)-CZ(K+44))/CZ(I+45)*ADCP(I)
      DO 69 I=1,9
      FMTB(I)=0.0
      AMTB(I)=0.0
      FMQB(I)=0.0
   69 AMQB(I)=0.0
      FMTB(1)=SIMPUN(B(15),FDMT(1),9)
      AMTB(1)=SIMPUN(CZ(46),ADMT(1),9)
      FMQB(1)=SIMPUN(B(15),FDMQ(1),9)
      AMCB(1)=SIMPUN(CZ(46),ADMQ(1),9)
      FMTB(3)=SIMPUN(B(17),FDMT(12),7)
      AMTB(3)=SIMPUN(CZ(48),ADMT(12),7)
      FMQB(3)=SIMPUN(B(17),FDMQ(12),7)
      AMQB(3)=SIMPUN(CZ(48),ADMQ(12),7)
      FMTB(5)=SIMPUN(B(19),FDMT(23),5)
      AMTB(5)=SIMPUN(CZ(50),ADMT(23),5)
      FMQB(5)=SIMPUN(B(19),FDMQ(23),5)
      AMCB(5)=SIMPUN(CZ(50),ADMQ(23),5)
      FMTB(7)=SIMPUN(B(21),FDMT(34),3)
      AMTB(7)=SIMPUN(CZ(52),ADMT(34),3)
      FMQB(7)=SIMPUN(B(21),FDMQ(34),3)
      AMCB(7)=SIMPUN(CZ(52),ADMQ(34),3)
      DO 70  I=1,9
      FMTB(I)=FNMT*FMTB(I)
      AMTB(I)=ANMT*AMTB(I)
      FMQB(I)=FNMQ*FMQB(I)
   70 AMQB(I)=ANMQ*AMQB(I)
      DO 71 I=1,9
      FMXO(I)=FMTB(I)*COS(CZ(I+36))+FMQB(I)*SIN(CZ(I+36))
      AMXO(I)=AMTB(I)*COS(CZ(I+90))+AMQB(I)*SIN(CZ(I+90))
      FMYO(I)=FMTB(I)*SIN(CZ(I+36))-FMQB(I)*COS(CZ(I+36))
   71 AMYO(I)=AMTB(I)*SIN(CZ(I+90))-AMQB(I)*COS(CZ(I+90))
       IF(JPR.NE.2) GO TO    91
      WRITE (6,12)
      WRITE (6,13)KO
      WRITE (6,72)
   72 FORMAT(52X,14HFORE PROPELLER//)
      WRITE (6,73 )FCT,FCP,FCPT,FFE,FCOC
   73 FORMAT(9H      CTS=1PE10.4,9H      CPS=1PE10.4,9H      CTP=1PE10.4,9H
     1       EF=1PE10.4,13H      CTS/CPS=1PE10.4)
```

```
      WRITE (6,74)
   74 FORMAT(1H )
      WRITE (6,74)
      WRITE (6,75)
   75 FORMAT (17X,2HXI,8X,7HEPSILON,7X,3HMTB,9X,3HMQB,9X,3HMXO,9X,3HMYO,
     110X,1HM,9X,4HG(M))
      WRITE (6,74)
   91 KO=KO+1
      DO 92 I=1,9
   92 QA(I,1)=QA(I,1)/0000FL
      IF(JPR.NE.2) GO TO    94
      DO 76 I=1,9
   76 WRITE (6,77 )B(I+14),FLD(I),FMTB(I),FMQB(I),FMXO(I),FMYO(I),I,QA(I
     1,1)
   77 FORMAT(12X,1P6E12.4,6X,I1,5X,E12.4)
      WRITE (6,74)
      WRITE (6,74)
      WRITE (6,74)
      WRITE (6,78)
   78 FORMAT(53X,13HAFT PROPELLER//)
      WRITE (6,73 )ACT,ACP,ACPT,AFE,ACOC
      WRITE (6,74)
      WRITE (6,75)
      WRITE (6,74)
   94 DO 93 I=1,9
   93 CG(I,1)=CG(I,1)/B(11)
      IF(JPR.NE.2) GO TO    22
      DO 79 I=1,9
   79 WRITE (6,77 )CZ(I+45),ALD(I),AMTB(I),AMQB(I),AMXO(I),AMYO(I),I,CG(
     1I,1)
      WRITE (6,80)
   80 FORMAT(1H //////)
      WRITE (6,81)
   81 FORMAT(57X,5HTOTAL///)
      WRITE (6,73 )TFCT,TFCP,TCTP,TFFE,TCOC
   82 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SUB1
      DIMENSION CZ(108),TL(12),B(99),AP(9,9),AQ(9,9),AU(9,9),AW(9,9),AX(
     19,9),AY(9,9),QA(9,9),FT(9),CG(9,1)
      DIMENSION P(81),AH(10,9)
      DIMENSION AJ(9,9),AL(9),AO(9,9),AR(9,9),AS(9,9),AT(9,9),AV(9,9),AZ
     1(9,9),C(9),E(9),F(9),G(9),H(81),BA(9,9),BB(9,9),BC(9,9),BD(9,9),BE
     2(9,9),BF(9,9),BG(9,9),BH(9,9),WA(9,9),XA(9,9)
      DIMENSION CF(9,1),CH(9,9),CI(9,1)
      DIMENSION BK(9),BS(9),CD(10,9),Q(9),O(81)
      DIMENSION INDEX(9,3)
      COMMON  CZ     , TL     , B      , AP     , AQ     , AU
      COMMON  AW     , AX     , AY     , QA     , FT     , CG
      COMMON  BQ     , BY     , KO     , MB     , CMP ,WA,XA
      CA=4.0
      DO 4 I=1,9
      C(I)=((1.0+B(15))-2.0*B(I+14))/(1.0-B(15))
      AH(2,I)=C(I)
      CE=C(I)**2
      ABC=(1.0-CE)
      IF(ABC)1,2,3
    1 ABC=-ABC
      GO TO 3
    2 ABC=.0001
    3 CD(2,I)=SQRT(ABC)
      AH(1,I)=1.0
    4 CD(1,I)=0.0
      AH(2,1)=1.0
      AH(2,9)=-1.0
      CD(2,1)=0.0
      CD(2,9)=0.0
      DO 5 J=3,10
      L=J-1
      DO 5 K=1,9
      AH(J,K)=(AH(L,K)*AH(2,K))-(CD(L,K)*CD(2,K))
    5 CD(J,K)=(CD(L,K)*AH(2,K))+(AH(L,K)*CD(2,K))
      DO 6 I=2,8
    6 E(I)=3.1415927/CD(2,I)
      RSL=B(7)/(3.1415927*B(4)*B(2))
      IF (B(51)-0.0) 9,7,9
    7 DO 8 J=1,9
    8 B(J+50)=RSL/(B(J+14)*B(5))*SQRT(B(9)*B(J+23))
    9 DO 10 J=1,9
   10 F(J)=B(12)*B(J+50)
   11 DO 12 J=1,9
   12 G(J)=1.0/F(J)
      DO 13 I=1,9
      JNO=I-1
      DO 13 J=1,9
      K=9*JNO+J
   13 H(K)=B(I+14)/B(J+14)*G(J)
      DO 14 J=1,9
   14 Q(J)=ATAN(F(J))
      DO 25 N=1,9
      KNO=N-1
      LNO=N-1
      MNO=N-1
```

```
      DO 25 I=1,9
      J=9*MNO+I
      IF(H(J)-G(I)) 16,15,16
   15 K=9*KNO+I
      L=9*LNO+I
      O(K)=COS(Q(I))
      P(L)=SIN(Q(I))
      GO TO 25
   16 S=1.0+H(J)**2
      T=SQRT(S)
      V=1.0+G(I)**2
      W=SQRT(V)
      AE=T-W
      U=EXP(AE)
      R=((((T-1.0)/H(J)*(G(I)/(W-1.0)))*U)**B(10)
      AC=1.5
      AD=.25
      X=(1.0/(2.0*B(10)*G(I)))*((V/S)**AD)
      Y=((9.0*G(I)**2)+2.0)/(V**AC)+((3.0*H(J)**2-2.0)/(S**AC))
      Z=1.0/(24.0*B(10))*Y
      IF(H(J)-G(I))  21,21,17
   17 AF=1.0+1.0/(R-1.0)
      IF(AF)18,19,20
   18 AF=-AF
      GO TO 20
   19 AF=.0001
   20 AA=X*(1.0/(R-1.0)-Z*ALOG(AF))
      K=9*KNO+I
      L=9*LNO+I
      O(K)=2.0*B(10)**2*G(I)*H(J)*(1.0-G(I)/H(J))*AA
      P(L)=B(10)*(1.0-G(I)/H(J))*(1.0+2.0*B(10)*G(I)*AA)
      GO TO 25
   21 AG=1.0+1.0/(1.0/R-1.0)
      IF(AG)22,23,24
   22 AG=-AG
      GO TO 24
   23 AG=.0001
   24 AB=-X*(1.0/(1.0/R-1.0)+Z*ALOG(AG))
      K=9*KNO+I
      L=9*LNO+I
      O(K)=B(10)*G(I)*(1.0-H(J)/G(I))*(1.0-2.0*B(10)*G(I)*AB)
      P(L)=2.0*B(10)**2*G(I)*(1.0-G(I)/H(J))*AB
   25 CONTINUE
      DO 26 I=1,9
      IMO=I-1
      DO 26 L=1,9
      K=9*IMO+L
   26 AP(L,I)=O(K)
      DO 27 I=1,9
      JMO=I-1
      DO 27 L=1,9
      K=9*JMO+L
   27 AQ(L,I)=P(K)
      DO 28 I=1,9
      DO 28 L=1,9
   28 AJ(L,I)=AH(I,L)
      DO 29 I=1,9
```

```
      DO 29 L=1,9
29    AO(L,I)=AH(I,L)
      CALL MATINS(AJ,9,9,AP,9,9,DETERM,ID,INDEX)
      IF(ID-1)30,32,30
30    PRINT 31
      GO TO 110
31    FORMAT (26H I(A) IS SINGULAR FOR Z(F))
32    CALL MATINS(AO,9,9,AQ,9,9,DETERM,ID,INDEX)
      IF(ID-1)33,35,33
33    PRINT 34
      GO TO 110
34    FORMAT (25H I(T) IS SINGULAR OF Z(F))
35    AS(1,1)=AP(1,1)+AP(2,1)
      DO 36 J=2,8
36    AS(J,1)=AS(J-1,1)+AP(J+1,1)
      AS(9,1)=AS(8,1)
      DO 37 L=1,9
37    AW(L,1)=FLOAT(L)*AS(L,1)
      DO 38 L=2,9
      K=L-1
38    AU(K,1)=AP(L,1)*FLOAT(K)
      AU(9,1)=0.0
      AV(9,1)=0.0
      DO 39 L=2,9
      J=10-L
39    AV(J,1)=AV(J+1,1)+AU(J+1,1)
      DO 40 L=1,9
40    AZ(L,1)=(AW(L,1)+AV(L,1))*3.1415927
      DO 41 I=2,8
      DO 41 L=2,9
      K=L-1
41    AR(K,I)=AP(L,I)*AH(L,I)
      DO 43 I=2,8
      AS(1,I)=AP(1,I)*AH(1,I)+AR(1,I)
      DO 42 J=2,9
      K=J-1
42    AS(J,I)=AS(K,I)+AR(J,I)
43    AS(9,I)=AS(8,I)
      DO 44 I=2,8
      DO 44 L=1,9
      J=L+1
44    AW(L,I)=CD(J,I)*AS(L,I)
      DO 46 I=2,8
      DO 45 L=2,9
      K=L-1
45    AU(K,I)=AP(L,I)*CD(L,I)
46    AU(9,I)=0.0
      DO 47 I=2,8
      AV(9,I)=0.0
      DO 47 L=2,9
      J=10-L
47    AV(J,I)=AV(J+1,I)+AU(J+1,I)
      DO 48 I=2,8
      DO 48 L=1,9
      J=L+1
48    AX(L,I)=AH(J,I)*AV(L,I)
      DO 49 I=2,8
```

```
      DO 49 L=1,9
   49 AZ(L,I)=(AW(L,I)+AX(L,I))*F(I)
      DO 50 L=1,4
      J=2*L
   50 AP(J,9)=-1.0*AP(J,9)
      AR(1,9)=AP(1,9)+AP(2,9)
      DO 51 L=2,8
   51 AR(L,9)=AR(L-1,9)+AP(L+1,9)
      AR(9,9)=AR(8,9)
      DO 52  L=1,9
   52 AS(L,9)=FLOAT(L)*AR(L,9)
      DO 53  L=2,9
      K=L-1
   53 AU(K,9)=FLOAT(K)*AP(L,9)
      AU(9,9)=0.0
      AV(9,9)=0.0
      DO 54  L=2,9
      J=10-L
   54 AV(J,9)=AV(J+1,9)+AU(J+1,9)
      DO  55 L=1,9
   55 AZ(L,9)=(AS(L,9)+AV(L,9))*3.1415927
      DO 56  L=1,4
      J=2*L
   56 AZ(J,9)=-1.0*AZ(J,9)
      BA(1,1)=AQ(1,1)+AQ(2,1)
      DO 57  J=2,8
   57 BA(J,1)=BA(J-1,1)+AQ(J+1,1)
      BA(9,1)=BA(8,1)
      DO 58  L=1,9
   58 BB(L,1)=FLOAT(L)*BA(L,1)
      DO 59  L=2,9
      K=L-1
   59 BC(K,1)=AQ(L,1)*FLOAT(K)
      BC(9,1)=0.0
      BD(9,1)=0.0
      DO  60 L=2,9
      J=10-L
   60 BD(J,1)=BD(J+1,1)+BC(J+1,1)
      DO 61  L=1,9
   61 BH(L,1)=(BB(L,1)+BD(L,1))*3.1415927
      DO  62 I=2,8
      DO  62 L=2,9
      K=L-1
   62 BA(K,I)=AQ(L,I)*AH(L,I)
      DO 64  I=2,8
      BB(1,I)=AQ(1,I)*AH(1,I)+BA(1,I)
      DO 63  J=2,9
      K=J-1
   63 BB(J,I)=BB(K,I)+BA(J,I)
   64 BB(9,I)=BB(8,I)
      DO 65  I=2,8
      DO 65  L=1,9
      J=L+1
   65 BC(L,I)=CO(J,I)*BB(L,I)
      DO 67  I=2,8
      DO 66  L=2,9
      K=L-1
```

```
66 BD(K,I)=AQ(L,I)*CD(L,I)
67 BD(9,I)=0.0
   DO 68  I=2,8
   BE(9,I)=0.0
   DO 68  L=2,9
   J=10-L
68 BE(J,I)=BE(J+1,I)+BD(J+1,I)
   DO 69  I=2,8
   DO 69  L=1,9
   J=L+1
69 BF(L,I)=AH(J,I)*BE(L,I)
   DO 70  I=2,8
   DO 70  L=1,9
70 BH(L,I)=(BC(L,I)+BF(L,I))*E(I)
   DO 71  L=1,4
   J=2*L
71 AQ(J,9)=-1.0*AQ(J,9)
   BA(1,9)=AQ(1,9)+AQ(2,9)
   DO 72  L=2,8
72 BA(L,9)=BA(L-1,9)+AQ(L+1,9)
   BA(9,9)=BA(8,9)
   DO 73  L=1,9
73 BB(L,9)=FLOAT(L)*BA(L,9)
   DO 74  L=2,9
   K=L-1
74 BC(K,9)=FLOAT(K)*AQ(L,9)
   BC(9,9)=0.0
   BD(9,9)=0.0
   DO 75  L=2,9
   J=10-L
75 BD(J,9)=BD(J+1,9)+BC(J+1,9)
   DO 76  L=1,9
76 BH(L,9)=(BB(L,9)+BD(L,9))*3.1415927
   DO 77  L=1,4
   J=2*L
77 BH(J,9)=-1.0*BH(J,9)
   T=3.0
   DO 78 J=1,9
78 CF(J,1)=(B(J+23)-(B(J+14)/RSL*F(J)))*(1.0-B(15))
   DO 79 J=1,9
79 H(J)=CF(J,1)*RSL/((1.0-B(15))*B(J+14))-F(J)
   DO 80 M=1,9
   DO 80 I=1,9
80 AT(I,M)=(H(I)*BH(M,I)-AZ(M,I))*(FLOAT(M)/B(10))
81 DO 82 J=1,9
82 O(J)=(G(J)+H(J))/B(J+14)*((1.0-B(15))/2.0)
   DO 83  J=1,9
83 CG(J,1)=CF(J,1)
   DO 84 M=1,9
   L=M+1
   DO 84 I=1,9
84 AP(I,M)=CD(L,I)*O(I)
   DO 85 I=1,9
   DO 85 J=1,9
85 AQ(J,I)=AT(J,I)-AP(J,I)
   DO 86  J=1,9
   DO 86  K=1,9
```

```
 86 CH(K,J)=AQ(K,J)
    CALL MATINS(AQ,9,9,CG,1,1,DETERM,ID,INDEX)
    IF(ID-1)87,89,87
 87 PRINT 88
    GO TO 110
 88 FORMAT (27H G(MX) IS SINGULAR FOR Z(F))
 89 DO 91 J=1,9
    SUMUA=0.0
    SUMAU=0.0
    DO 90 L=1,9
    SUMUA=SUMUA+FLOAT(L)*CG(L,1)*AZ(L,J)
 90 SUMAU=SUMAU+FLOAT(L)*CG(L,1)*BH(L,J)
 91 AU(J,1)=SUMUA/SUMAU
    S=.005
    DO 94 J=1,9
    CI(J,1)=AU(J,1)-G(J)
    IF(CI(J,1))92,93,93
 92 CI(J,1)=-1.0*CI(J,1)
 93 BW=S-CI(J,1)
    IF(BW)95,94,94
 94 CONTINUE
    GO TO 101
 95 T=T-1.0
    IF(T)98,96,96
 96 DO 97 J=1,9
 97 G(J)=AU(J,1)
    GO TO 81
98      CONTINUE
200     FORMAT(9F12.4)
 99 FORMAT (20H TOO MANY ITERATIONS)
100 FORMAT (12A6)
101 DO 103 J=1,9
    SUMUT=0.0
    DO 102 K=1,9
102 SUMUT=SUMUT+FLOAT(K)*CG(K,1)*BH(K,J)
103 AW(J,1)=SUMUT/(B(10)*(1.0-B(15)))
    DO 105 J=1,9
    SUMUA=0.0
    DO 104 K=1,9
104 SUMUA=SUMUA+FLOAT(K)*CG(K,1)*AZ(K,J)
105 AX(J,1)=SUMUA/(B(10)*(1.0-B(15)))
    DO 107 J=1,9
    SUMG=0.0
    DO 106 K=1,9
    L=K+1
106 SUMG=SUMG+CG(K,1)*CO(L,J)
107 AY(J,1)=SUMG
    AY(1,1)=0.0
    AY(9,1)=0.0
    DO 108 I=1,9
    BO=AY(I,1)**2/(2.0*B(I+14))
    BV=B(I+14)/RSL
108 BK(I)=((BV-AW(I,1))*AY(I,1)+BO)*8.0
    BL=SIMPUN(B(15),BK(1),9)
    BY=BL
    BM=B(2)**2
    BP=B(7)**2
```

```
      BQ=(8.0*B(6)/(B(8)*BM*3.1415927*BP))
  109 MB=1
      GO TO 111
  110 MB=2
  111 RETURN
      END
```

```
      SUBROUTINE SUB2(CC,FB,FC,FD,HR,IPO)
      DIMENSION CZ(108),TL(12),B(99),AP(9,9),AQ(9,9),AU(9,9),AW(9,9),AX(
     19,9),AY(9,9),QA(9,9),FT(9),CG(9,1)
      DIMENSION TABX(9),TABY(9),FB(9,8),FC(9,8),FD(9,8),FU(9),FV(9),FW(9
     1),HA(9,9),XA(9,9)
      DIMENSION FE(9),FF(9),FM(9),FP(9),FQ(9),FR(9),FS(9)
      DIMENSION FX(9),FY(9),GA(9),GB(9),GC(9),GD(9),GF(9),GG(9),GH(9),HV
     1(9),GI(9),GK(9),GL(9),GM(9),GN(9),HE(9),HK(9),HL(9),HP(9),HQ(9),HS
     2(9)
       COMMON /WRT/ JPR
      DIMENSION HE1(9),GC1(9)
      COMMON  CZ      , TL      , B       , AP      , AQ      , AU
      COMMON  AW      , AX      , AY      , QA      , FT      , CG
      COMMON  BQ      , BY      , KO      , MB      , CMP ,WA,XA
    1 RSL=B(7)/(3.1415927*B(4)*B(2))
    2 GU=3.0
      DO 4  J=1,9
    4 FE(J)=FD(J,4)/(2.0*B(J+14)*FB(J,4))
      DO 6  J=1,9
    6 FF(J)=FD(J,8)/(2.0*B(J+14)*FB(J,8))
      FI=0.0
      FJ=0.0
      FK=1.0
    7 DO 12 J=1,9
    8 FG=FC(J,4)*FE(J)
    9 FH=FC(J,8)*FF(J)
   10 FL=(FH*(1.0-B(J+41)))*FK
   12 FM(J)=B(J+23)+FG+FL
      DO 16 J=1,9
   13 FN=FK*FC(J,8)*FF(J)
   14 FO=FC(J,4)*FE(J)*(1.0+B(J+41))
   16 FP(J)=B(J+32)+FN+FO
      DO 18 J=2,9
   18 FQ(J)=1.0-(FM(J)/FP(J))
      FQ(1)=0.0
   19 GO=(B(16)-B(15))/2.0
      FR(1)=0.0
      DO 21 J=2,9
      GO=(B(J+14)-B(J+13))/2.0
   21 FR(J)=(FQ(J-1)+FQ(J))*B(J+14)*GO
      FS(1)=0.0
      DO 23 J=2,9
   23 FS(J)=FS(J-1)+FR(J)
      FT(1)=0.0
      DO 25 J=2,9
   25 FT(J)=FS(J)/(B(J+14)**2)
      GV=0.0
      DO 27 J=2,9
   27 GV=GV+FT(J)
      FI=GV/9.0
   28 FK=(1.0+FI)*(1.0+FJ)
      DO 30 J=1,9
   30 FU(J)=FK*FC(J,8)*FF(J)*(1.0-B(J+41))
      DO 32 J=1,9
   32 FV(J)=B(J+23)+FC(J,4)+FU(J)
      DO 34 J=1,9
```

```
      GQ=FK*FC(J,8)
      GR=FC(J,4)*FE(J)*(1.0+B(J+41))
   34 FW(J)=B(J+32)+GQ+GR
      DO 37 J=1,9
   35 GS=FW(J)/FP(J)
   37 FX(J)=(FV(J)/(FW(J)*GS))-1.0
      GT=0.0
      DO 39 J=1,9
   39 GT=GT+FX(J)
      FJ=GT/9.0
      GU=GU-1.0
   40 IF (GU) 42,41,41
   41 FK=(1.0+FI)*(1.0+FJ)
      GO TO 7
   42 DO 46 J=1,9
   43 FY(J)=B(J+14)/RSL
   44 FZ=FV(J)-FC(J,4)
   46 GA(J)=FZ/FY(J)
      DO 48 J=1,9
   48 GB(J)=FV(J)/(FY(J)-FB(J,4))
      DO 50 J=1,9
   49 GC(J)=ATAN(GB(J))
   50 GC1(J)=ATAN(GB(J))*57.2957795
      DO 53 J=1,9
   51 HD=2.0*3.1415927/CC
   53 GD(J)=HD*(FD(J,4)/FV(J))*SIN(GC(J))
      DO 55 J=1,9
   55 GF(J)=FD(J,4)/CC
      DO 60 J=1,9
   56 GW=(FV(J)/SIN(GC(J)))**2
   57 GY=2.0*CC/3.1415927
   58 GG(J)=GY*GD(J)*GW*COS(GC(J))
   60 GH(J)=GY/RSL*GD(J)*GW*SIN(GC(J))*B(J+14)
      DO 64 J=1,9
   61 HU=B(3)-(B(J+14)*B(2)/2.0)
   62 HW=(SIN(GC(J))/(B(7)*FV(J)))**2
   64 HV(J)=64.31*HU*HW
      DO 66 J=1,9
   66 GI(J)=((1.0-FT(J))/(1.0-FT(9)))*B(J+14)
      DO 68 J=1,9
   68 GK(J)=GI(J)*(1.0-FT(9))/RSL
      DO 72  J=1,9
   69 GL(J)=2.0*FB(J,4)*FE(J)*(1.0+FT(J))
   70 GZ=B(J+32)+FC(J,4)*FE(J)*(1.0+B(J+41))
   72 GM(J)=GZ/(GK(J)+GL(J))
      DO 74 J=1,9
   74 GN(J)=FW(J)/(GK(J)-FK*FB(J,8)+GL(J))
      DO 76 J=1,9
   75 HE(J)=ATAN(GN(J))
   76 HE1(J)=ATAN(GN(J))*57.2957795
      DO 81 J=1,9
   77 HF=2.0*3.1415927/B(11)
   78 HI=FD(J,8)/FW(J)
   79 HJ=(1.0+FX(J))/(1.0-FT(9))
   81 HK(J)=HF*HI*HJ*SIN(HE(J))
      DO 84 J=1,9
   82 HM=B(11)*B(J+32)*(1.0-FT(9))
```

```
84 HL(J)=(FD(J,8)*(1.0+FX(J)))/HM*B(J+32)
   DO 85 J=1,9
   HN=2.0*B(11)/3.1415927
   HO=(FW(J)/SIN(HE(J)))**2
   HP(J)=HN*HK(J)*HO*COS(HE(J))
85 HQ(J)=HN/RSL*HK(J)*HO*SIN(HE(J))*GI(J)*(1.0-FT(9))
86 HR=(1.0-FT(9))*B(2)
   DO 90 J=1,9
87 HT=B(3)-GI(J)*HR/2.0
88 HW=(SIN(HE(J))/(B(7)*FW(J)))**2
   CTSIF=SIMPUN(B(15),GG,9)
   CPSIF=SIMPUN(B(15),GH,9)
   CTSIA=SIMPUN(GI,HP,9)
   CPSIA=SIMPUN(GI,HQ,9)
   B(80)=CTSIF+(1.0-FT(9))**2*CTSIA
90 HS(J)=64.31*HT*HW
    IF(JPR.NE.2) GO TO    120
   IF(CMP)107,107,91
91 WRITE (6,92)
92 FORMAT(1H1)
   WRITE (6, 93)TL
93 FORMAT (12A6)
   WRITE (6,  94)KO
94 FORMAT (110X,5HPAGE I2)
   WRITE (6, 95)HR
95 FORMAT(60H                                                    D-A
  1    1PE12.4)
   WRITE (6, 96)FI
96 FORMAT(60H                                                  DELTA
  1BAR 1PE12.4)
   WRITE (6, 97)FT(9)
97 FORMAT(60H                                                DELTA X
  1OF 11PE12.4)
   WRITE (6, 98)FJ
98 FORMAT(60H                                                   ZETA
  1BAR 1PE12.4)
   WRITE (6, 99)
   WRITE (6, 99)
99 FORMAT (5H0    )
   WRITE (6, 100)
100 FORMAT(53X,13HFWD PROPELLER//)
   WRITE (6, 101)B(70),CTSIF,CPSIF
101 FORMAT(8H      K=1PE10.4,8H   CTSI=1PE10.4,8H   CPSI=1PE10.4)
   WRITE (6, 99)
   WRITE (6,102)
102 FORMAT(5X,4HX(F),5X,10HTAN BETA-I,3X,8HTAN BETA,5X,5HCLL/D,8X,4HG(
  1S),6X,6HUT/2VS,6X,6HUA/2VS,7X,5HDCTSI,7X,5HDCPSI,6X,7HSIGMA X//)
   DO 103J=1,9
103 WRITE (6,104)B(J+14),GB(J),GA(J),GD(J),GF(J),FB(J,4),FC(J,4),GG(J)
  1,GH(J),HV(J)
104 FORMAT(10(1PE12.4))
   WRITE (6, 99)
   WRITE (6, 99)
   WRITE (6, 105)
   WRITE (6, 101)CZ(100),CTSIA,CPSIA
   WRITE (6, 99)
105 FORMAT(53X,13HAFT PROPELLER//)
```

```
      WRITE (6,102)
      DO 106 J=1,9
106   WRITE (6,104)GI(J),GN(J),GM(J),HK(J),HL(J),FB(J,8),FC(J,8),HP(J),H
     1O(J),HS(J)
120   KO=KO+1
107   DO  108I=1,9
      CZ(I)=GB(I)
      CZ(I+9)=GD(I)
      CZ(I+18)=GG(I)
      CZ(I+27)=GH(I)
      CZ(I+36)=GC1(I)
      CZ(I+45)=GI(I)
      CZ(I+54)=GN(I)
      CZ(I+63)=HK(I)
      CZ(I+72)=HP(I)
      CZ(I+81)=HO(I)
108   CZ(I+90)=HE1(I)
      DO  109I=1,9
      TABX(I)=B(I+14)
109   TABY(I)=B(I+70)
      DO  110I=1,9
      X=GI(I)
      CALL DISCOT (X,X,TABX,TABY,TABY,30,9,0,Y)
110   B(I+70)=Y
      GO TO 111
111   RETURN
      END
```

```
      SUBROUTINE MATINS(A,NR,N1,B,NC,M1,DETERM,ID,INDEX)
      EQUIVALENCE (IROW,JROW), (ICOLUM,JCOLUM), (AMAX, T, SWAP)
                          DIMENSION  A(NR,NR),  B(NR,NC),  INDEX(NR,3)
C
C      INITIALIZATION
C
      N=N1
      M=M1
      DETERM = 1.0
      DO 20 J=1,N
   20 INDEX(J,3) = 0
      DO 550 I=1,N
C
C     SEARCH FOR PIVOT ELEMENT
C
      AMAX = 0.0
      DO 105 J=1,N
      IF(INDEX(J,3)-1) 60, 105, 60
   60 DO 100 K=1,N
      IF(INDEX(K,3)-1) 80, 100, 715
   80 IF (      AMAX -ABS  (A(J,K))) 85, 100, 100
   85 IROW=J
      ICOLUM =K
      AMAX = ABS (A(J,K))
  100 CONTINUE
  105 CONTINUE
      INDEX(ICOLUM,3) = INDEX(ICOLUM,3) +1
      INDEX(I,1)=IROW
      INDEX(I,2)=ICOLUM
C
C     INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL
C
      IF (IROW-ICOLUM) 140, 310, 140
  140 DETERM=-DETERM
      DO 200 L=1,N
      SWAP=A(IROW,L)
      A(IROW,L)=A(ICOLUM,L)
  200 A(ICOLUM,L)=SWAP
      IF(M) 310, 310, 210
  210 DO 250 L=1, M
      SWAP=B(IROW,L)
      B(IROW,L)=B(ICOLUM,L)
  250 B(ICOLUM,L)=SWAP
C
C     DIVIDE PIVOT ROW BY PIVOT ELEMENT
C
  310 PIVOT    =A(ICOLUM,ICOLUM)
      DETERM=DETERM*PIVOT
  330 A(ICOLUM,ICOLUM)=1.0
      DO 350 L=1,N
  350 A(ICOLUM,L)=A(ICOLUM,L)/PIVOT
      IF(M) 380, 380, 360
  360 DO 370 L=1,M
  370 B(ICOLUM,L)=B(ICOLUM,L)/PIVOT
C
C     REDUCE NON-PIVOT ROWS
C
```

```
  380 DO 550 L1=1,N
      IF(L1-ICOLUM) 400, 550, 400
  400 T=A(L1,ICOLUM)
      A(L1,ICOLUM)=0.0
      DO 450 L=1,N
  450 A(L1,L)=A(L1,L)-A(ICOLUM,L)*T
      IF(M) 550, 550, 460
  460 DO 500 L=1,M
  500 B(L1,L)=B(L1,L)-B(ICOLUM,L)*T
  550 CONTINUE
C
C     INTERCHANGE COLUMNS
C
      DO 710 I=1,N
      L=N+1-I
      IF (INDEX(L,1)-INDEX(L,2)) 630, 710, 630
  630 JROW=INDEX(L,1)
      JCOLUM=INDEX(L,2)
      DO 705 K=1,N
      SWAP=A(K,JROW)
      A(K,JROW)=A(K,JCOLUM)
      A(K,JCOLUM)=SWAP
  705 CONTINUE
  710 CONTINUE
      DO 730 K = 1,N
      IF(INDEX(K,3) -1) 715,720,715
 720   CONTINUE
 730   CONTINUE
       ID = 1
 810  RETURN
 715  ID = 2
       GO TO 810
       END
```

```
      SUBROUTINE GMHAS(NP,NH,Y,R)
C
C     GMHAS, A FORTRAN IV VERSION OF SHARE SUBROUTINE AM GMHAS,
C     PROGRAMMED FOR IBM 360 CONVERSION.
C
C     PROGRAMMER - M. GOLDEN, CODE 892, 8-20-68.
C
C-------- ALGORITHM ---------------------------------------------------
C
C     FOR A SET OF Y(I) POINTS (0.LE.I.LE.K-1), WHICH CORRESPOND TO A
C     SET OF EQUALLY SPACED X(I) POINTS, COMPUTE THE A(J), B(J), C(J),
C     AND PHI(J) TERMS OF THE FOLLOWING SERIES, WHERE H IS THE NUMBER
C     OF HARMONICS DESIRED.
C
C              H
C     Y=A(0)+SUM(A(J)*COS(J*X)+B(J)*SIN(J*X))
C             J=1
C
C        OR
C
C              H
C     Y=A(0)+SUM(C(J)*SIN(J*X+PHI(J)))
C             J=1
C
C     WHERE C(J) IS THE AMPLITUDE AND PHI(J) IS THE PHASE ANGLE OF THE
C     JTH. HARMONIC.  THE FUNCTION IS ASSUMED PERIODIC WITH Y(0)=Y(K).
C
C-------- ARGUMENT DEFINITION -----------------------------------------
C
C     1. NP - THE NUMBER OF INPUT POINTS ( K ABOVE ).
C     2. NH - THE NUMBER OF HARMONICS DESIRED ( H ABOVE ).
C     3. Y  - THE SET OF INPUT POINTS DESCRIBED ABOVE.
C     4. R  - THE OUTPUT ARRAY, WHICH CONTAINS A(0),B(0),C(0),PHI(0),
C      C(0)/C(MAX),A(1),...,A(NH),B(NH),C(NH),PHI(NH),C(NH)/C(MAX).
C
C-------- RESTRICTIONS ------------------------------------------------
C
C     1. R MUST BE DIMENSIONED AT LEAST 5*(NH+1)+2 IN THE CALLING
C      PROGRAM.
C     2. Y MUST BE DIMENSIONED AT LEAST NP IN THE CALLING PROGRAM.
C
C-------- NOTES -------------------------------------------------------
C
C     1. R(5*NH+6) CONTAINS THE CHECKSUM
C
C                K/2
C     Y(0)=A(0)+SUM(A(J)) FOR H EVEN
C                J=1
C
C        OR
C
C             (K-1)/2
C     Y(0)=A(0)+SUM(A(J)) FOR H ODD.
C                J=1
C
C     2. R(5*NH+7) CONTAINS THE CHECKSUM
C
```

```
C                   K/2-1
C     Y(1)-Y(K-1)=2*SUM(B(J)*SIN(J*ALPHA(0)))  FOR H EVEN
C                    J=1
C
C         OR
C
C                   (K-1)/2
C     Y(1)-Y(K-1)=2*SUM(B(J)*SIN(J*ALPHA(0)))  FOR H ODD
C                    J=1
C
C     3. ALPHA IS DEFINED AS 2*PI/K
C     4. ALL ARGUMENTS ARE SINGLE-PRECISION, AND ALL COMPUTATIONS ARE
C      DOUBLE-PRECISION.
C     5. THE CHECKSUMS WILL NOT BE COMPUTED IF A FULL-POINT ANALYSIS
C      IS NOT MADE.
C     6. THE PHI*S ARE IN DEGREES, NOT RADIANS.
C     7. THE SIGN OF PHI(0) (AND PHI(K/2) IF COMPUTED) IS MADE TO AGREE
C      WITH THE SIGN OF A(0) (AND A(K/2)).
C     8. PHI(I) IS NOT COMPUTED FOR A(I)=B(I)=0, FOR 1.LE.I.LE.NH.
C
C------------------------------------------------------------------
C
      DIMENSION Y(1),R(1)
      DOUBLE PRECISION C,C1,C2,S,S1,XNP,ANGLE,ALPHA
      EQUIVALENCE (S,C)
C
C
C     ZERO THE OUTPUT ARRAY.
C
      NH1=5*NH+7
      DO 10 I=1,NH1
   10 R(I)=0.
C
C     COMPUTE ALL CONSTANTS
C
      C1=360./6.2831853
      XNP=NP
      C2=2./XNP
      ALPHA=6.2831853/XNP
C
C     COMPUTE A(0), B(0)=0, C(0), AND PHI(0).
C
      S=0.
      DO 20 I=1,NP
   20 S=S+Y(I)
      R(1)=S/XNP
C
C     COMPUTE A(I), B(I), C(I), PHI(I) FOR 1.LE.I.LE.K/2-1
C
      DO 40 I=1,NH
      S=0.
      S1=0.
      DO 30 J=1,NP
      ANGLE=ALPHA*FLOAT((J-1)*I)
      S=S+Y(J)*DCOS(ANGLE)
   30 S1=S1+Y(J)*DSIN(ANGLE)
      I1=5*I+1
```

```
      R(I1)=S*C2
      R(I1+1)=S1*C2
      C=R(I1)**2+R(I1+1)**2
      R(I1+2)=DSQRT(C)
      R(I1+4)=R(I1+2)
C
C     DO NOT COMPUTE PHI(I) IF A(I)=B(I)=0.
C
      IF(R(I1).NE.0..OR.R(I1+1).NE.0.)GO TO 32
      WRITE(6,31)I,I
   31 FORMAT(///16H TO COMPUTE PHI( I4,46H),IT WOULD BE NECESSARY TO COM
     1PUTE ATAN2(0,0)./48H THESE ARGUMENTS WILL NOT BE ACCEPTABLE, SO PH
     2I( I4,23H) WILL NOT BE COMPUTED.///)
      GO TO 40
   32 R(I1+3)=C1*ATAN2(R(I1),R(I1+1))
   40 CONTINUE
C
C     COMPUTE A(K/2), B(K/2)=0, C(K/2), PHI(K/2) IF H IS EVEN.
C     DO NOT COMPUTE THEM IF H IS ODD OR A FULL-POINT ANALYSIS IS
C     NOT COMPUTED.
C
      IF(MOD(NP,2).NE.0)GO TO 60
      IF((2*NH).NE.(2*(NP/2)))GO TO 60
      AI=-1.
      S=0.
      DO 50 I=1,NP
      AI=-AI
   50 S=S+AI*Y(I)
      NH1=5*NH+1
      R(NH1)=S/XNP
      R(NH1+2)=ABS(R(NH1))
      R(NH1+4)=R(NH1+2)
      R(NH1+1)=0.
      R(NH1+3)=SIGN(90.,R(NH1))
C
C     COMPUTE CMAX.
C
   60 C=0.
      NH1=NH+1
      DO 70 I=1,NH1
   70 C=DMAX1(C,DBLE(R(5*I)))
C
C     COMPUTE C(I)/CMAX FOR 0.LE.I.LE.NH.
C
      DO 80 I=1,NH1
      I1=5*I
   80 R(I1)=R(I1)/C
C
C     COMPUTE THE CHECKSUMS IF A FULL-POINT ANALYSIS WAS COMPUTED.
C
      IF((2*NH).NE.(2*(NP/2)))RETURN
      I1=5*NH1+1
      DO 90 I=1,NH1
   90 R(I1)=R(I1)+R(5*I-4)
      I1=I1+1
      IF(MOD(NP,2).EQ.0)NH1=NH1-1
      DO 100 I=2,NH1
```

```
100 R(I1)=R(I1)+R(5*I-3)*DSIN(FLOAT(I-1)*ALPHA)
    R(I1)=2.*R(I1)
    RETURN
    END
```

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